Maryland's GreenPrint Program:

Summary of Methods to Identify and Evaluate Maryland's Green Infrastructure

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GENERAL OVERVIEW

What is Maryland's GreenPrint program?

Saving our diverse and ecologically precious natural resources is the basis for Maryland's GreenPrint Program. GreenPrint will allow the State of Maryland to preserve an extensive, intertwined network of land vital to the long term survival of our native plants and wildlife, and certain industries which rely on a clean, healthy environment and abundant natural resources.

Today, Maryland has only two million acres of ecologically significant land that has not been consumed by sprawl development. Of these two million acres of "green infrastructure," almost three-quarters are unprotected. Billions of dollars are spent each year to construct or maintain the state's built infrastructure of roads, bridges and utilities that we depend on for modern life. By contrast, the state's green infrastructure, which exists naturally, is under tremendous pressure from development. Left unprotected, the remaining green infrastructure is vulnerable and will be further reduced and fragmented.

Maryland's GreenPrint Program will help protect the ecological vitality found in each region of the state, including forests, parks, greenways, and wetlands, preserving and enhancing it for future generations. By acting now, Maryland can ensure cleaner air and cleaner water for its citizens and safeguard habitat to spare native waterfowl, animals, and plants from extinction.

Maryland's GreenPrint Program signifies a bold new direction in land conservation. The purpose of the program is threefold:

- Identify, using state-of-the-art computer mapping techniques, the most important unprotected natural lands in the state;
- Link, or connect, these lands through a system of corridors or connectors; and
- Save those lands through targeted acquisitions and easements.

Green Infrastructure

Maryland's green infrastructure has been mapped using sophisticated satellite imaging technology, with the results being reviewed by scientists, local government officials, and conservation groups. The first step identified the heart of our green infrastructure called "Green Hubs." These are typically sweeping areas hundreds of acres in size and are vital to maintaining the state's vibrant and unique ecology. The second step connected Green Hubs with "Green Links" - corridors, as they are referred to in the scientific literature, like stream valleys and mountain ridge lines that function as "Habitat Highways."

Within the Green Infrastructure in Maryland are:

- Forest: 1,552,529 acres
- Interior forest: 956,443 acres
- Wetlands: 497,416 acres *(note- some wetlands are also forests)*
- Bare rock or sand, such as beaches: 1,644 acres
- Streams in interior forest: 2,468 miles
- Natural Heritage Areas: 39,186 acres
- Wetlands of Special State Concern: 59,768 acres

Green Hubs, Green Links & the Habitat Highway

As Maryland continues to grow we must prevent the shrinking and fragmentation of undeveloped open space. By fortifying and restoring the green infrastructure, the state can maximize the ecological potential of Maryland's landscape. In Green Hubs, our distinctive wildlife will have access to a full range of habitat enabling animals to flourish amidst vast stretches of protected lands. Green Hubs also reduce the stress placed on our forests, helping to renew woodlands and preventing their collapse into isolated pockets of trees.

Strings of Green Links will form Habitat Highways, natural routes bridging Green Hub to Green Hub. Maryland's Habitat Highways will allow wildlife safe passage through their natural domain; facilitate seed and pollen transport helping plant life thrive across the state; and keep streams and wetlands healthy by protecting adjacent vegetation. Preserving linkages between the remaining large habitat areas will ensure the long term survival and continued diversity of Maryland's natural resources and environment.

How will Maryland's GreenPrint program build upon our current land conservation programs?

Over the past several years, the State of Maryland has enacted several effective land conservation programs. These include the Open Space and Rural Legacy programs, a variety of agricultural preservation efforts, private conservation easement agreements, and regulations that help preserve wetlands and shorelines. As a result, Maryland is known nationally as a leader in land conservation and natural resource protection. While these initiatives proved effective in addressing specific needs related to wetlands, endangered species, recreation, and farmland, they were not designed to protect a comprehensive network of ecologically sensitive lands. Despite our successes, only 26% of the identified green infrastructure is already protected.

The GreenPrint Program will build upon existing conservation programs by:

- Providing urgently needed additional funding to act immediately;

- Conserving and connecting large contiguous land areas with multiple important natural resource features;
- Providing a focal point to coordinate existing conservation programs with one another and increase their overall effectiveness; and
- Guiding and coordinating land conservation and preservation efforts, just as Priority Funding Areas guide Smart Growth development.

Why do these lands need protection by GreenPrint?

Because much of the state's key natural resource land has been lost, Maryland needs to protect as much as possible of what remains. The benefits of the GreenPrint Pogram include:

- Fills a critical gap in current land conservation efforts by targeting resources to important ecological lands;
- Ensures the continuation of natural services in each region that help clean the air and water;
- Supports Maryland's economy, especially the forest products industry, Maryland's seafood industry, and nature tourism.
- Reduces the need for expensive stormwater management, flood control, and restoration projects by protecting water resources including streams, wetlands, and riparian corridors; and
- Addresses commitments in the new Chesapeake Bay Agreement to protect 20% of the watershed and to reduce the rate of sprawl development by 30%.

In addition to their ecological and economic contributions, these lands provide a sense of place and a unique identity. Natural landscapes make communities more comfortable and appealing and link current generations to their heritage and cultural past.

Why should I care about Maryland's GreenPrint?

GreenPrint impacts all Maryland citizens. For some people, like watermen and those who harvest and process timber, it affects their jobs. For others, the green infrastructure provides places for hobbies, recreational activities, and learning opportunities. Our children and teachers can, together, learn the wonders of nature by using the green infrastructure as a living classroom. Nature lovers can enjoy hiking, camping, observing, and photographing all forms of plant and wildlife.

Developers, private landowners, and others will benefit from having a clear understanding of where the most ecologically valuable lands are located, and where targeted conservation activities will be directed. Citizens interested in increased stewardship activities will know where their efforts are most needed.

Land planners and developers can use the green infrastructure maps as a reference in the development of site plans and management objectives.

Local governments will be able to enhance their efforts to provide open space, recreation lands, and natural areas that retain the unique character of their communities and rural landscapes. The GreenPrint Program will complement their efforts to direct growth to specified areas.

Private land trusts will have another tool at their disposal. Conservation groups, and their members, will find that Maryland's GreenPrint Program will give them a greater impact where it means the most – on the ground, in the water, and in the air.

For everyone who lives in or visits Maryland, GreenPrint is a way to preserve our rich quality of life and safeguard, for future generations, Maryland's Chesapeake Bay and the legacy of Maryland's special natural landscapes: the picturesque, rolling mountains of Western Maryland; the forest lands and wooded wetlands of Southern Maryland; the expansive native marshes of our Eastern Shore; and the diverse and rich stream valleys of our Western Shore and Piedmont region. Action is needed now to ensure that our children, our grandchildren, and generations to come, have the same opportunities to enjoy Maryland's outstanding natural resources and high quality of life as we do today.

BACKGROUND AND LITERATURE REVIEW

This chapter summarizes some of the scientific literature which formed the foundation on which Maryland's Green Infrastructure Assessment was predicated. It includes a brief look at what is happening to Maryland's landscape that makes such an assessment timely and suggests the management implications of a program to focus on preservation of the state's remaining green infrastructure.

BACKGROUND FOR THE MODEL

Underlying the entire assessment of green infrastructure in Maryland is the growing concern, reflected in a substantial body of scientific literature, for the importance of entire ecosystems to supporting human use of the landscape and of the interconnectedness of all of the parts. Ecological process and this interconnectedness have replaced previous emphasis on protection of particular species, or of geographic areas having direct human utility, in conservation planning. The growing body of science underlies the model used to identify the important components of Maryland's green infrastructure.

The importance of natural land

Maryland's undeveloped lands provide the bulk of the state's natural support system. Ecosystem services, such as cleaning the air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants, regulating climate, protecting areas against storm and flood damage, and maintaining hydrologic function, are all provided by the existing expanses of forests, wetlands, and other natural lands (Conservation Fund, 2000). These ecologically valuable lands also provide marketable goods and services, like forest products, fish and wildlife, and recreation. They serve as vital habitat for wild species, maintain a vast genetic library, provide scenery, and contribute in many ways to the health and quality of life for Maryland residents.

A study by Costanza et al (1997) estimated the economic value of 17 ecosystem services (see Table 1) for 16 biomes, based on published studies and original calculations. A minimum estimate of the global total was between $16-54 trillion per year (1994 U.S. dollars), with an average of $33 trillion per year, almost twice the global Gross National Product (GNP) (Costanza et al, 1997). The average value for some ecosystems occurring in Maryland is listed in Table 2. It should be emphasized that these are average global estimates, and not specific to the state. DNR is currently working with the University of Maryland to compute local ecosystem values to the economy.

Table 1. Ecosystem services and functions evaluated by Costanza et al (1997)

Ecosystem service	Ecosystem functions	Examples
Gas regulation	Regulation of atmospheric chemical composition.	CO_2/O_2 balance, O_3 for UVB protection, and SO_x levels.
Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels.	Greenhouse gas regulation, DMS production affecting cloud formation.
Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations.	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure.
Water regulation	Regulation of hydrologic flows.	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation.
Water supply	Storage and retention of water.	Provisioning of water by watersheds, reservoirs and aquifers.
Erosion control and sediment retention	Retention of soil within an ecosystem.	Prevention of loss of soil by wind, runoff, or other removal processes; storage of silt in lakes and wetlands.
Soil formation	Soil formation processes.	Weathering of rock and the accumulation of organic material.
Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients.	Nitrogen fixation, N, P and other elemental or nutrient cycles.
Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.	Waste treatment, pollution control, detoxification
Pollination	Movement of floral gametes.	Provisioning of pollinators for the reproduction of plant populations.
Biological control	Trophic-dynamic regulations of populations.	Keystone predator control of prey species, reduction of herbivory by top predators.
Refugia	Habitat for resident and transient populations.	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds.

Ecosystem service	Ecosystem functions	Examples
Food production	That portion of gross primary production extractable as food.	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming, or fishing.
Raw materials	That portion of gross primary production extractable as raw materials.	The production of lumber, fuel or fodder.
Genetic resources	Sources of unique biological materials and products.	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants).
Recreation	Providing opportunities for recreational activities.	Eco-tourism, sport fishing, hunting, birdwatching, hiking, camping, canoeing, and other outdoor recreational activities.
Cultural	Providing opportunities for non-commercial uses.	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems.

Table 2. Average economic value (U.S. dollars per acre per year) of ecosystem services estimated by Costanza et al (1997), for select biomes occurring in Maryland.
Numbers were adjusted from 1994 US$ to estimated mid-2001 US$ using the Gross Domestic Product Deflator inflation index.

Biome	Average global value of annual ecosystem services ($/ac/yr)
Temperate/boreal forests	134
Tidal marsh	4,456
Swamps/floodplains	8,734
Lakes/rivers	3,790
Estuaries	10,184
Seagrass/algae beds	8,477
Continental shelf	719

Conserving forests and wetlands can help local governments and other public agencies reduce costs from flooding and other natural hazards (McQueen, 2000). According to a study by American Forests (American Forests, 1999), tree loss in the Baltimore-Washington urban corridor between 1973 and 1997 resulted in a 19% increase in stormwater runoff (540 million cubic feet). Replacing the lost stormwater retention capacity with engineered systems would have cost $1.08 billion (American Forests, 1999). Total stormwater retention capacity of the area's forest in 1997 was worth $4.68 billion (American Forests, 1999). The lost trees would also have removed 9.3 million pounds of air pollutants annually at a value of $24 million per year (American Forests, 1999).

In some parts of the U.S., attention has focused on the benefits of protecting natural watersheds to assure safe and plentiful drinking water supplies, rather than on building expensive filtration plants to purify water from degraded watersheds (World Resources Institute, 1998). New York City recently avoided spending $6-8 billion in constructing new water treatment plants by protecting the upstate watershed that has traditionally accomplished these purification services for free (World Resources Institute, 1998). Based on this economic assessment, the city invested $1.5 billion in buying land around its reservoirs and instituting other protective measures, actions that will not only keep its water pure at a bargain price but also enhance recreation, wildlife habitat, and other ecological benefits (World Resources Institute, 1998).

Maryland's changing landscape

The population and developed portions of Maryland have grown rapidly. Between 1790 and 1990, Maryland's population grew from 320,000 to 4,780,000 (RESI, 1997). The increase was 13.4% between 1980 and 1990 alone (RESI, 1997). Maryland's population is projected to increase an additional 24.4% between 1995 and 2025 (RESI, 1997). Developed land has increased even faster than the population. Before colonization by Europeans, Maryland was 95% forested, the other 5% being marsh around Chesapeake Bay (Besley, 1916; Powell and Kingsley, 1980). By 1993, forest had decreased to 47% of land area (from MRLC). Virtually all of this is secondary regrowth; as far back as 1916, less than 1% was virgin forest (Besley, 1916). Similarly, Maryland has lost 50% of its pre-settlement wetlands (Tiner and Burke, 1995). Since automobiles became the primary source of transportation, people began migrating from large cities like Baltimore, and suburbs have sprawled across the landscape. Between 1985 and 1990 alone, developed land use increased by 18.6%, to 921,000 acres (RESI, 1997). The Maryland Department of Planning has projected urban land use to increase by more than 25% by 2020 from 1997 levels.

This development has come primarily at the expense of agriculture and forest. American Forests (1999) found that average tree cover in the Chesapeake Bay watershed declined from 51% to 39% between 1973 and 1997. Natural tree cover (areas with at least 50% tree cover) declined from 55% to 38% of the total area (American Forests, 1999). The Maryland Department of Planning has projected forest cover to decrease a further 9% by 2020 from 1997 levels. Agriculture has also been projected to decrease by 9% during the same period. Wildlife habitat and migration corridors are being lost, and normal ecosystem functions such as absorption of nutrients, recharging of water supplies, and replenishment of soil are being disturbed or destroyed. Water quality has been degraded in numerous streams and rivers, as well as the Chesapeake Bay itself. Many of Maryland's remaining wetlands have been altered by filling, drainage, impoundment, livestock grazing, logging, direct discharges of industrial wastes and municipal sewage, freshwater diversions, and non-point discharges such as urban and agricultural runoff (Tiner and Burke, 1995).

The scattered pattern of modern development not only consumes an excessive amount of land, it fragments the landscape. Sorrell (1997) states, "the end result of fragmentation is often a patchwork of small, isolated islands of habitat in a sea of developed land". Numerous studies have shown the negative ecological effects of forest fragmentation in the landscape. Some generalist or ecotone species, like white-tailed deer and raccoons, can benefit from fragmentation. But according to Sorrell (1997), habitat fragmentation is perhaps the greatest worldwide threat to forest wildlife, and the primary cause of species extinction. Yahner (1988), Hansen and Urban (1992), Donovan et al (1995), and Robinson et al (1995) showed that fragmentation and increased edge have reduced the distribution and abundance of forest birds and other wildlife species throughout North America. As forest areas are divided and isolated by roads and development, interior habitat decreases, human disturbance increases, opportunistic edge species replace interior species, and populations of many animals become too small to persist.

Habitat loss and fragmentation have contributed greatly to a continuing loss of biodiversity in Maryland. At least 180 plant and 35 animal species have been extirpated from Maryland, including elk, gray wolves, bison, and mountain lions (Williams, 1991). Another 310 plant and 165 animal species are rare, threatened, or endangered (Williams, 1991).

Habitat patches and edge effects

A "patch" can be defined as a contiguous part of the landscape, with comparable length and width, that is distinguished by discontinuities in its environmental characteristics from its surroundings (Wiens, 1976; White and Pickett, 1985; Forman and Godron, 1986). In wildlife ecology, these environmental gradients are ones noticeable to animals, and will be perceived differently by different species (Wiens, 1976; Lidicker, 1999).

A patch edge is the outer band of the patch that is influenced by surrounding environmental conditions, and is thereby significantly different from the interior (Forman and Godron, 1986). Edges are most pronounced between greatly dissimilar ecotypes, like forest and row crops, or wetland and parking lot. Edges produced by humans tend to be straighter and more abrupt than those created naturally. For a given shape, the smaller the patch, the greater its perimeter to area ratio, and thus the more dominant boundary effects become.

Forest edges contain significant gradients of solar radiation, temperature, wind speed, and moisture between the forest patch interior and the adjacent land, especially if the adjacent land is developed (Forman and Godron, 1986; Brown et al, 1990). Increased solar radiation at the edge increases temperatures and decreases soil moisture and, with increased wind flow, decreases relative humidity (Forman and Godron, 1986; Brown et al, 1990). This can desiccate plants. Increased wind speed at a newly created edge commonly knocks down trees that are no longer buffered by adjacent canopy and not structurally prepared (Brown et al, 1990). This poses a problem especially for wetland trees, which have shallow roots and less stable soil (Brown et al, 1990). Wind can also carry dust or other small particles, which can adhere to vegetation (Brown et al, 1990). Noise from developed land disrupts natural activity in adjacent forest or marsh, by drowning wildlife cues for territorial boundary establishment, courtship and mating behavior, detection of separated young, prey location, predator detection, and homing (Yahner, 1988; Brown et al, 1990). Sudden loud noises can also cause stress to animals (Brown et al, 1990). Clearcuts adjacent to forest can also cause excess runoff, erosion, nutrient loss, and loss of wildlife (Harris, 1984). They can also increase the chance and severity of fire. For example, the weed-brush stage is the successional stage most subject to fire in Douglas fir forests (Harris, 1984).

Changes in insolation and other physical parameters at created edges change plant and animal communities there, and processes like nutrient cycling (Forman and Godron, 1986; Brown et al, 1990). Edge habitat differs from interior forest in tree species composition, primary production, structure, development, animal activity, and propagule dispersal capabilities (Brown et al, 1990; Kapos et al, 1993). The edge communities shift to more shade-intolerant, more xeric tree and shrub species, and early successional species (Brown et al, 1990). These then broadcast propagules that invade the forest interior (Brown et al, 1990). Edges created by human or natural disturbances can favor invasive exotic species like reed canary grass (*Phalaris arundinacea*), garlic mustard (*Alliaria petiolata*), Japanese honeysuckle (*Lonicera japonica*), or multiflora rose (*Rosa multiflora*), which can then displace native species in adjacent areas (Lidicker, 1999; Maryland DNR Wildlife and Heritage Division,1999; USDA NRCS, 1999).

Opportunistic animals like raccoons, opossums, and cowbirds also often invade the interior from edges, and often prey on, outcompete, or parasitize interior species (Reese and Ratti, 1988; Robinson, 1988; Brown et al, 1990; Dunning et al, 1992; Heske et al, 1999). Increased nest predation may extend 300 to 600 meters inside the forest (Reese and Ratti, 1988; Yahner, 1988; Brown et al, 1990). Cowbirds parasitize bird nests up to 1000 feet from the forest edge (Reese and Ratti, 1988; Brown et al, 1990). Several species of birds have been severely affected by cowbird parasitism, including the endangered Kirtland's warbler (*Dendroica kirtlandii*) and the possibly now extinct Bachman's warbler (*Vermivora bachmanii*) (Harris, 1988; U.S. Fish and Wildlife Service, 1997). Cats and dogs from developed areas can prey on or harass wildlife. House cats, which hunt on instinct, range large areas (30-228 ha); one cat studied with a regular diet of domestic food killed over 1600 mammals and 60 birds during an 18 month period (Brown et al, 1990).

Measures of edge and buffer widths

Harris (1984), Brown et al (1990), and Kapos et al (1993) cite a distance of 2-3 tree heights from the forest edge to reduce the effects of sunlight and wind penetration. This translates to about 300 feet in Maryland, and could be considered the abiotic transition zone. However, some forest interior birds nest further from the edge than this (Bushman and Therres, 1988). Further, Gates and Evans, in a study of brown-headed cowbirds in 1996, detected 94% of female breeding fixes within 220 m of forest edges. They defined interior forest as $250 m (820 ft) from the edge. About 60% of telemetry fixes were within 50 m of the edge (Gates and Evans, 1996). Since females travel up to 10 km between breeding and feeding areas (avg was 2.3 km), they were abundant even in Western Maryland state parks (Gates and Evans, 1996). However, the abiotic transition zone is more applicable to forested ecosystems as a whole. Thus, in Maryland, blocks of interior forest habitat should be buffered at least 300 feet, preferably by forest with similar native composition and structure.

Wetland buffers also perform important functions, including (Brown et al, 1990; North Carolina State University, 1998):

- sediment removal and erosion control,
- nutrient transformation and removal,
- metals and other pollutant reduction,
- stormwater runoff reduction through infiltration,
- reduction of water temperature,
- reduction of human impacts by limiting easy access and by minimizing edge effects from noise, light, temperature, and other changes,
- protection against water table drawdown from adjacent ditches,
- providing a wetland-upland ecotone that is utilized by numerous species of wildlife,
- protection for interior wetland species, and
- a barrier to invasion of nuisance and exotic species.

The necessary buffer width will vary according to individual site by type of wetland, sensitivity to disturbance, intensity of adjacent land use, groundwater depth and hydraulic conductivity, proximity and characteristics of drainage ditches and other water control structures, slope and soil characteristics, species present, and buffer characteristics such as vegetation density and structural complexity, soil condition, etc. (Brown et al, 1990; North Carolina State University, 1998). Brown et al (1990) recommended varying buffer widths for wetlands in different landscapes of east central Florida. The distance to minimize groundwater drawdown varied from 20 to 550 feet, to control sedimentation, 75 to 375 feet, and to protect wildlife habitat, 322 to 732 feet (Brown et al, 1990). Brown et al (1990) recommended a wildlife buffer of 550 feet for forested wetlands and 322 feet for emergent wetlands. A literature search of studies on specific buffer performance “found that for sediment removal, necessary widths ranged from 10 to 60 m; for nutrient and metals removal, widths ran from 4 to 85 m; for species distribution and diversity protection, from 3 to 110 m was required; and for water temperature moderation, requirements ranged from 15 to 28 m” (North Carolina State University, 1998). Castelle et al. recommended minimum buffer widths around 30 m under most circumstances to provide both basic physical and chemical buffering to maintain biological components of wetlands and streams (North Carolina State University, 1998). They noted that fixed-width buffer approaches are easier to enforce, but that variable-width buffers are more likely to provide adequate protection on a specific-case basis (North Carolina State University, 1998). A minimum 90 meter buffer around state and federal wildlife refuges and conservation areas has been recommended (North Carolina State University, 1998).

Streams are strongly dependent on the surrounding terrestrial environment, which serves as both a buffer and a source of organic matter, especially for small (low-order) streams (Harding et al, 1998). Natural vegetation in the riparian zone has been shown to stabilize stream hydrology; maintain the integrity of stream channels and shorelines; intercept nutrients, sediment, and chemicals; moderate water temperature, and supply food, cover and thermal protection to fish, amphibians, invertebrates, and other wildlife (Harding et al, 1998; Maryland Department of Natural Resources, 1999; Chesapeake Bay Program, 2000). The Chesapeake Bay Program (Chesapeake Bay Program, 2000) recommends a three-zone buffer for streams, with the width of each zone determined by site conditions.

Riparian forests provide the best stream buffers; some of their benefits are quoted below from Chesapeake Bay Program (2000):

- Filtering runoff: Rain that runs off the land can be slowed and infiltrated in the forest, which helps settle out sediment, nutrients and pesticides before they reach streams. Infiltration rates 10-15 times higher than grass turf and 40 times higher than a plowed field are common in forested areas. Studies have shown dramatic reductions of 30 percent to 98 percent in nutrients (nitrogen and phosphorus), sediment, pesticides, and other pollutants in surface and groundwater after passing through a riparian forest. In addition, trees provide deep root systems which hold soil in place, thereby stabilizing streambanks and reducing erosion.
- Nutrient uptake: Fertilizers and other pollutants that originate on the land are taken up by tree roots. Nutrients are stored in leaves, limbs and roots instead of reaching the stream. Through a process called denitrification, bacteria in the forest floor convert harmful nitrate to nitrogen gas, which is released into the air.
- Canopy and shade: Cool stream temperatures maintained by riparian vegetation are essential to the health of aquatic species. Shading moderates water temperatures and protects against rapid fluctuations that can harm stream health and reduce fish spawning and survival. Elevated temperatures also accelerate algae growth and reduce dissolved oxygen, further degrading water quality. In a small stream, temperatures may rise 1.5 degrees in just 100 feet of exposure without trees. The leaf canopy also improves air quality by filtering dust from wind erosion, construction or farm machinery.
- Leaf food: Leaves fall into a stream and are trapped on woody debris (fallen trees and limbs) and rocks where they provide food and habitat for small bottom-dwelling

creatures (such as crustaceans, amphibians, insects and small fish), which are critical to the aquatic food chain.

- Habitat: Riparian forests offer a tremendous diversity of habitat. The layers of habitat provided by trees, shrubs, and grasses and the transition of habitats from aquatic to upland areas make these areas critical in the life stages of over half of all native Bay species. Forest corridors provide crucial migratory habitat for neotropical songbirds, some of which are now threatened due to loss of habitat. Also, many ecologically important species such as herons, wood ducks, black ducks, as well as amphibians, turtles, foxes and eagles utilize the riparian forest. Streams that travel through woodlands provide more habitat for migratory fish by providing suitable spawning habitat for shad, herring, alewife, perch, and striped bass. The decline of these species is partly due to destruction of habitat, which for some, like shad and herring, extends well into small streams. Trees and woody debris provide valuable cover for crabs, small fish and other aquatic organisms along the Bay's shoreline as well. Degradation of any portion of a stream can have profound effects on living resources downstream. While the overall impact of these riparian forest corridors may be greatest in headwaters and smaller order streams, there is a clear linkage all the way to the Bay.

The effect of patch size and isolation on biodiversity

According to island biogeography theory (MacArthur and Wilson, 1967; Harris, 1984; Forman and Godron, 1986), species richness in landscape patches depends on patch area: $S = cA^z$; where S is the species diversity, A is the patch area, and c and z are constants. In the absence of compensating colonization, species become extinct in small patches faster than in larger patches (MacArthur and Wilson, 1967; Harris, 1984; Harris, 1988; Hanski, 1997). Larger patches support a larger variety of habitats, are more likely to be noticed or stumbled on by colonists, support larger populations, which are less vulnerable to extinction, and support animals that require large home ranges (Brown et al, 1990; Hanski, 1997). Small patches in fragmented landscapes may act as ecological traps by concentrating populations of birds or other animals in areas with insufficient resources, as well as concentrating predators (Heske, 1999). Landscapes with a few, small, isolated patches can be dominated by edge effects, and provide little viable habitat for interior species (With and King, 1999).

According to Bushman and Therres (1988), 250 acres is the minimum forest size to maintain a viable breeding population of 7 forest interior birds of Maryland. 8 required smaller contiguous forest blocks, and 3 required more. Top carnivores, many of which have been extirpated from Maryland, require large foraging areas. Top predators are especially important because they act as ecosystem regulators (Soule and Terbough,1999). In their absence, trophic structures can become destabilized, with consumers and mesopredators becoming more abundant, and floral recruitment and diversity decreasing (Soule and Terbough,1999). Brown et al (1990) lists home range requirements for individuals of many wildlife species. Viable populations require much more area than a single individual. A viable population is one that has a high probability (e.g., 95 or 99 percent) of persisting for a long time (e.g., for 100 to 1000 years) (Noss, 1992). In most cases, viable populations are generally on the order of thousands of individuals (Noss, 1992).

Harris (1984) studied the fragmentation of old-growth forest in the Pacific Northwest. He found that as old-growth habitat patches became isolated from similar surrounding habitat, species with ranges beyond the patch were extirpated, and the number of species reduced (Harris, 1984). Isolation also decreases plant diversity, which further decreases animal diversity (Harris, 1984). Fragmentation can also interfere with seasonal movements, such as salamanders moving to ponds to breed (Loehle, 1999).

The species most vulnerable to extinction in fragmented landscapes have small populations: large animals with large home ranges (e.g., top carnivores), ecological specialists, and species with variable populations that depend on patchy or unpredictable resources (Harris, 1984; Harris, 1988; Brown et al, 1990; Hanski, 1997). Models by Tilman and Lehman (1997) showed that habitat destruction tends to extirpate species that are superior competitors but poor dispersers. The Baltimore County Department of Environmental Protection and Resource Management (1996) summarized studies of species types most affected by forest fragmentation. These include naturally rare species, wide-ranging species, nonvagile species, species with low fecundity, species dependent on patchy or unpredictable resources, species that are highly variable in population size, ground nesters, and interior forest species. For example, Gibbs (1998) found that low densities, fluctuating populations, high mobility, and specialized habitat needs make woodland amphibians vulnerable to local extinction caused by habitat fragmentation.

As patch size decreases, and as patches of habitat become more isolated, population sizes, especially of rare species, may decrease below the threshold needed to maintain genetic variance, withstand stochastic events and population oscillations, and meet social requirements like breeding and migration (Harris, 1984; Bowne et al, 1999). The size needed to prevent adverse genetic drift is probably higher than the size needed to withstand oscillations (Harris, 1984). Inbreeding within small populations increases the chance that progeny will receive duplicate alleles from a common ancestor, which can lower the vigor and fecundity of species within a few generations, and limit adaptation to changing environmental conditions (Brown et al, 1990). The size needed to ensure genetic flexibility is even higher; this therefore determines the minimum population size (Harris, 1984; Vrijenhoek, 1985). Shrinkage and isolation of the Florida panther's range led to inbreeding and a 95% level of sperm infertility (Harris, 1988). Harris (1984) states that conservation should allow evolution of populations, species, and ecosystems, so they are more adaptive to change. Sufficient genetic variability is required for adaptive flexibility and future evolution; species should be conserved before their numbers drop low enough where they are endangered (Harris, 1984).

Species richness in isolated "islands" also depends on their distance to a "mainland" source of colonizers (MacArthur and Wilson, 1967), or in general, the probability of recolonization. Metapopulations are systems of local populations spread throughout the landscape, connected by dispersing individuals (Levins, 1969; Hanski and Gilpin, 1991). Many species with a formerly continuous spatial distribution are turned into metapopulations by habitat fragmentation, as long as they are able to maintain stable local populations somewhere, and disperse successfully enough to recolonize extirpated areas (Hanski and Gilpin, 1991). Some habitat patches support stable populations of a particular species, dependent on both deterministic characteristics (patch size, abiotic composition, biotic community, etc.) and stochastic events (disturbance, population fluctuations, etc.). Patches with stable populations become "sources" of dispersing individuals, whereas less favorable habitat patches may be "sinks", and maintain their populations only by immigration from source patches (Wiens, 1976; Pulliam, 1988; Hanski and Gilpin, 1991; Wells and Richmond, 1995). Large contiguous habitat blocks, such as forest or wetland, appear to be population sources, and smaller fragments appear to be population sinks (Donovan et al, 1995). Local populations are often unstable, but new immigrants replace losses and revive the population (Smith, 1990). As a local population declines, a population elsewhere that is experiencing overcrowding supplies immigrants to other habitats (Smith, 1990). Increased distance between islands therefore decreases the survival chances of their populations (Smith, 1990; With and King, 1999). Numerous field studies have shown that the probability of a species colonizing an empty patch decreases with increasing isolation from existing nearby populations (Hanski, 1997).

Dispersal strategies of animals

Animal dispersal has potential genetic and somatic costs and benefits. It lowers inbreeding genetic depression, but also disrupts locally adapted genes, creates hybrid young that aren't as well locally adapted, and creates alleles less suited to the local environment. Dispersal increases individual fitness and fecundity by alleviating overcrowding, resource shortages, and competition with kin, but movement risks include predators, diseases, and unfamiliarity with the terrain. Also, a familiar social environment, locally adapted traditions, and kin associations are lost (Smith, 1990).

Presaturation dispersal is density-independent; it occurs before a population reaches the local carrying capacity. Dispersers are in good condition, are of any sex or age, and have a good chance of surviving to settle in a new area. In contrast, saturation dispersal is density-dependent; it occurs when a population exceeds the local carrying capacity. Dispersers are mostly juveniles and subdominants that must leave to establish their own home ranges, or perish or, at a minimum, not breed. Most dispersers die; "a few" settle in other areas (Smith, 1990).

Smith (1990) cites the rule of dispersal as "move to the first uncontested site you find and no further." A study of voles showed that if a barrier exists to prevent dispersal, or suitable habitat is not available for colonization, dispersers must return to their home area. Dispersers into optimal habitat had high survival and reproduction rates. Dispersers unable to colonize elsewhere, and having to return to their home area, had low survival rates. Females gained the most from decreased population density (Smith, 1990).

Successfully dispersing animals establish new territories usually several home range diameters away from the original (Forman and Godron, 1986). Animals rarely move in straight lines; rather, they meander (Forman and Godron, 1986). The route that permits the fastest movement is not always the shortest; for example, ridges and valleys are easier to navigate than slopes. Interior species prefer cover as they travel (Forman and Godron, 1986). For example, a study by St. Clair et al (1998) showed that over short distances, forest birds preferred wooded detours to open gaps, regardless of their efficiency. As distances increased, birds tended to employ shortcuts in the open when detour efficiency was low or initial distance in the open was high, but they stayed within 25 m of the nearest forest edge (St. Clair et al, 1998). Animals avoid large inhospitable patches like parking lots (Forman and Godron, 1986). The success of individuals in locating suitable habitat depends on the scale of movement relative to the scale of landscape patchiness (With and King, 1999). Dispersal has a decreasing chance of success as the distance between habitat patches exceeds the ability of the organism to either locate habitat or traverse gaps of unsuitable habitat (With and King, 1999).

The importance of corridors in a fragmented landscape

Landscape elements that link patches of the same element type (e.g., forest or marsh) together, and have a much longer length than width, are defined as "corridors" (White and Pickett, 1985; Forman and Godron, 1986). Corridors allow wildlife (terrestrial, wetland, and/or aquatic) to pass more easily between habitat blocks, thus increasing available habitat and animal populations (Forman and Godron, 1986; Harris, 1989). They also ease movement of native plant seeds. Corridors linking habitat patches in a landscape are essential for organisms to recolonize unoccupied sites, and for the persistence of metapopulations in fragmented landscapes (Dunning et al, 1992; Tilman et al., 1997; van Dorp et al, 1997; With and King, 1999). The closer the corridors resemble the habitat patches they connect, the more effective they are likely to be as conduits for the widest range of species (Lidicker, 1999).

The importance of corridors to a given species depends on its behavior and habitat requirements, on the age and sex of the individual, on the time of year, and on the nature of the surrounding matrix (St. Clair et al, 1998; Bowne et al, 1999; Szacki, 1999). Computer simulations by Fahrig (1997) and With and King (1999) demonstrated that the total amount of available habitat had a much greater effect on extinction probability than fragmentation, until <20% of habitat remained, at which point fragmentation became increasingly dominant. Studies of beetles, birds, and mammals cited by With and King (1999) showed similar results: fragmentation effects became important at a threshold of 10-30% habitat remaining. Below this, interpatch distances increase exponentially, and the spatial arrangement of patches becomes critical (With and King, 1999). Corridors may be less important to species with movement distances that are very short or very long relative to the landscape, where habitat is ephemeral, or where mortality rates in the matrix are low.

Bier and Noss (1998) reviewed published studies of corridor impacts on population viability. The evidence from well-designed studies demonstrated positive impacts of wildlife corridors on immigration rates, colonization rates, patch occupancy, and species diversity (Bier and Noss, 1998). Ten of the 12 studies allowing meaningful inferences of conservation value, offered persuasive evidence that corridors connecting habitats provide sufficient connectivity to improve population viability (Bier and Noss, 1998). None of the studies demonstrated negative impacts of conservation corridors (Bier and Noss, 1998).

Corridor arrangement and quality is also important to metapopulation survival. High connectivity, i.e., the arrangement of dispersal corridors between suitable habitat patches, allows organisms to better use a landscape's resources. Anderson and Danielson (1997) showed in simulations that connecting all patches with corridors, and maximizing the ratio of interior to peripheral patches, maximized metapopulation size. Adding additional connections had no effect. Patches connected by high-quality corridors (e.g., favorable habitat composition, sufficient width, few breaks, etc.) had few animals lost during dispersal, and stable metapopulations (Anderson and Danielson, 1997). In contrast, poor-quality corridors increased mortality, and decreased metapopulation size (Anderson and Danielson, 1997). Narrow corridors may be completely dominated by edge effects that expose native and migrating flora and fauna to reduced food availability, exotic species, increased predation, nest parasitism, human disturbance, and disease (Forman and Godron, 1986; Harris, 1989; Lidicker, 1999).

Van Dorp et al (1997) simulated the migration of perennial grassland species, and also demonstrated the importance of corridor presence and quality to the persistence of metapopulations. In narrow corridors, most of the dispersed seeds were deposited outside the corridor, which significantly reduced migration rates, especially for species with long-range seed dispersal (Van Dorp et al, 1997). In wide corridors, seed losses were much smaller, and migration rates approached those of continuous habitats (Van Dorp et al, 1997). Dispersal barriers such as corridor absence or gaps may prevent migration of short-range seed species (Van Dorp et al, 1997).

Percolation models by Tilman et al (1997) also showed the importance of corridors in fragmented landscapes. Corridor width was much more important than its length, especially for plant propagules and other organisms unable to adjust their behavior to stay within the corridor (Tilman et al., 1997). Passage of organisms may also be stopped if the corridor is too fragmented (Harris, 1989; Tilman et al., 1997; Lidicker, 1999), or if gaps in the corridor are too great (St. Clair et al, 1998).

The most successful corridors may be those that minimize transit times; this is a function of length, width, and presence of gaps (Lidicker, 1999). There may be an optimal width for each species. Too narrow, and use is inhibited (St. Clair et al, 1998). But too wide, transit time could be slowed by exploratory activity, or territories established and other individuals excluded (Lidicker, 1999). If true, this effect would be scale-dependent; a corridor could be too narrow for some species (e.g., black bears), and too wide for others (e.g., shrews). One solution to this dilemma might be considering width from an ecosystem perspective (e.g., forest with interior abiotic conditions) rather than species-specific perspectives.

The impact of roads on natural communities

Roads can fragment natural habitat like forests and wetlands, and convert interior habitat to edge habitat. For forests, this affects physical characteristics like insolation, moisture, wind, and noise; changes plant and animal communities, and alters ecosystem processes like nutrient cycling (Forman and Godron, 1986; Yahner, 1988; Brown et al, 1990; Kapos et al, 1993). Edge habitat created by roads allows edge-dwelling species of birds, other animals, and plants to penetrate previously closed forest cover. Such species are generally of less conservation concern than interior species, because human-dominated environments provide ample habitat for them (U.S. Forest Service, 1999). Edge species can also include predators or parasites such as the brown-headed cowbird (Reese and Ratti, 1988; Yahner, 1988; Brown et al, 1990).

Roads can also promote the invasion of exotic species. The U.S. Forest Service (1999) reported:

> "Building roads into a forest's interior and subsequently maintaining them (including ditch clearing, road grading, and vegetation clearing) represent disturbances that create and maintain new edge habitat. These roadside habitats can be invaded by a suite of exotic (non-native) plant species, which may be dispersed by natural agents such as wind and water as well as by vehicles and other agents related to human activity. Roads may be the first point of entry for exotic species into a new landscape, and the road can serve as a corridor along which the plants move farther into the landscape. Some exotic plants may then be able to move away from the roadside into adjacent patches of suitable habitat. Invasion by exotic plants may have significant biological and ecological effects if the species are able to disrupt the structure or function of an ecosystem. Invasion may also be of concern to land managers if the exotic species disrupt management goals and present costly eradication problems."

Roads act as a barrier, blocking plant and animal migration routes, and leading to species isolation (U.S. Forest Service, 1999). Where roads bisect wetlands or block streams, they inhibit the movement of aquatic or amphibian organisms. The movement, both successful and unsuccessful, of animals along or across roads depends on the width of the roadway, vehicle traffic, and the mobility and behavior of the species (Forman, 1995). Noise from roads can disrupt natural activity in adjacent areas (Yahner, 1988; Brown et al, 1990). Increases in night lighting either from roads, or adjacent development triggered by roadway expansion, also has a disruptive effect on wildlife (Schiller and DeLille, 1997). Narrow unpaved roads with few vehicles are often used at night by predators (Forman, 1995). However, paved roads strongly affect animal movement, from invertebrates to large mammals (Forman, 1995). Several studies show that the probability of small mammals crossing even lightly traveled roads of 6-15 m width is less than 10% of that for movement within the adjacent habitat (Forman, 1995). In another study, small forest mammals rarely crossed road corridors over 15 m wide (Forman, 1995). Mid-sized mammals crossed roadways up to 30 m wide, but never highway corridors of 118 and 137 m width (Forman, 1995). Large mammals cross most roads, but the rate of crossing is typically lower than movement in more favorable habitat (Forman, 1995). Amphibians and turtles exhibit reduced movement across roads (Forman, 1995). And some nesting birds and large mammals avoid the vicinity of roads altogether (Forman, 1995). Many studies have correlated increasing road density with wildlife avoidance, especially for large vertebrates (Forman, 1995; Mladenoff et al, 1995; U.S. Forest Service, 1999).

Road kills are a major population sink for terrestrial animals (Forman, 1995). An estimated one million vertebrates per day are killed on roads in the U.S. (U.S. Forest Service, 1999). The number of animal collisions with vehicles is directly related to the proximity of the nearest resting and feeding sites (U.S. Forest Service, 1999). Predators and scavengers may utilize sparsely-traveled roads as travel lanes, to seek prey where cover is interrupted, or to eat road-killed animals (Forman, 1995; U.S. Forest Service, 1999). They are thus vulnerable to vehicle collisions. Further, the large home ranges of carnivores often include road crossings (U.S. Forest Service, 1999). Road kill is a major source of bobcat mortality in Illinois (unpublished data). Small animals like amphibians, especially those that are slow moving or migratory, are even more vulnerable (U.S. Forest Service, 1999). Nearly all species of reptiles seek roads for cooling and heating, resulting in high mortality rates (U.S. Forest Service, 1999).

Roads separating home ranges or subpopulations may cause genetic isolation or local extirpation (Forman, 1995). Population sizes, especially of rare species, may decrease below the threshold needed to maintain genetic variance, withstand oscillations and meet social requirements like breeding and migration (Harris, 1984). The size needed to prevent adverse genetic drift is probably higher than the size needed to withstand oscillations (Harris, 1984).

Geomorphic effects of road construction include sedimentation associated with chronic or catastrophic erosion, the trapping of material from erosional processes further upslope, direct altering of drainage channel morphology, or modifying channel flowpaths and extending the drainage network into previously unchannelized areas (U.S. Forest Service, 1999). For paved roads, sedimentation mainly occurs during construction, when soils are exposed to water and wind runoff. Runoff of sediments to surface waters can cause adverse biological and hydrological effects such as increased embeddedness and stream channel alteration.

Other geomorphic effects include the filling and draining of wetlands. Wetlands fulfill numerous values to humans and functions in the landscape, including flood mitigation, storm abatement, aquifer recharge, water quality improvement, and habitat for numerous species (Mitsch and Gosselink, 1993). These functions are lost or degraded when filling or draining alters the hydrology.

The hydrologic effects of road construction not only include alteration of drainage morphology. Peak runoff volumes and flow rates from paved roads are greater than from vegetated soils due to the increased impervious surface area. Increased impervious surface also tends to decrease base flow downstream. Where roads bisect wetlands, ponding can occur on the uphill side, and drainage on the downhill side. This altered hydrology can affect plant and animal communities, nutrient cycling, soil development, and other wetland processes. Bridges, culverts, or other structures can mediate this problem if they make the roadway sufficiently permeable, and are maintained free of blockages.

The U.S. Forest Service (1999) found:

> "Roads have three primary effects on water: they intercept rainfall directly on the road surface and road cutbanks and subsurface water moving down the hillslope; they concentrate flow, either on the surface or in an adjacent ditch or channel; and they divert or reroute water from flowpaths that it would otherwise take if the road were not present. Most of the hydrologic and geomorphic consequences of roads result from one or more of these processes. For example, by intercepting surface and subsurface flow, and concentrating and diverting it into ditches, gullies, and channels, road systems effectively increase the the density of streams in the landscape, thereby changing the amount of time it takes for water to enter a stream channel, altering the timing of peakflows and hydrograph shape. Similarly, concentration and diversion of flow into headwater areas can cause incision of previously unchanneled portions of the landscape and inititate slides in colluvial hollows."

Roads can impact water quality as well. Oil, fuel, grease, antifreeze, pavement materials and other contaminants from vehicles can be washed into streams after rainstorms. In the winter, road salts can enter the environment through runoff from roads and storage sites, as well as disposal or dumping of snow containing road salts into snow piles or water bodies (Elliott, 1998). There is evidence of adverse effects to groundwater and to plant and animal life following exposure (Elliott, 1998). Algae and benthic fauna have been shown to be particularly sensitive to changes in chloride ion concentrations, resulting in a reduction of fish populations (Elliott, 1998). Roads also increase delivery of nutrients to streams by replacing vegetation with impervious surface.

Roads can affect aquatic communities via sedimentation, altering streamflow or channel configuration, changing water temperature by loss of riparian shade cover or conversion of ground water to surface water, acting as migration barriers, introducing disease or exotic species, lowering water quality, and increasing fishing pressure (U.S. Forest Service, 1999). At the landscape scale, roads can influence the frequency, timing, and magnitude of disturbance regimes, which can influence community structure and species diversity (U.S. Forest Service, 1999). Increased fine sediment composition in stream gravel has been shown to:

- decrease fry emergence;
- decrease juvenile fish density;
- lower winter carrying capacity by loss of concealment cover and increasing the likelihood of predation;
- reduce or eliminate populations of tailed frogs;
- reduce benthic organism populations; and,
- reduce algal production (U.S. Forest Service, 1999).

Road crossings are a common migration barrier to fish (U.S. Forest Service, 1999). Insufficient or improper culvert placement at road-stream crossings can reduce or eliminate fish passage (U.S. Forest Service, 1999). Blockages affect anadromous fish like American shad, yellow perch, and river herring by removing spawning habitat. Freshwater fish species can become extirpated from runs isolated by blockages.

Roads built adjacent to stream channels will increase water insolation and temperature if the riparian canopy is removed. This can sometimes have positive effects, such as increased food availability, but documented negative effects include elevation of stream temperatures beyond a species' tolerance, increased disease susceptibility, reduced metabolic efficiency, and shifts in species assemblages (U.S. Forest Service, 1999).

Other effects of roads cited by the U.S. Forest Service (1999) include:

- increasing disturbances from disease, fire, landslides, exotic species, etc;
- acting as fire breaks, which can be either positive or negative, depending on management objectives;
- soil and air pollution from vehicle emissions, chemical spills, dust, and other sources;
- lowering site productivity by altering soil properties, changing microclimate, and accelerating erosion; and,
- removing soil from productive use.

The effect of traffic noise and light depends on traffic volume and speed, height and density of adjacent cover, wind conditions, and other variables. Brown et al. (1990) reported that highway traffic noise is about 90 dB, and background noise levels in forested wilderness is about 35 dB under low wind conditions. Further, 15 dB below background noise is required to muffle human-caused sounds in wilderness areas (Brown et al., 1990). Vegetation may help to attenuate noise, but estimates for forest vary widely (between -1.5 dB per 100 feet and +15 dB per 100 feet), and attenuation by brush is almost negligible (Brown et al., 1990). Water can actually increase noise transmission (Brown et al., 1990). Ignoring the possible effects of adjacent cover and other factors, attenuation by spherical spreading is described by the equation $L_x = L_0 - 20 * \log(D_x/D_0)$, where L_x is the decibel level of the source to be calculated at a desired distance, L_0 is the decibel level of the source at a given distance, D_x is the distance from the source for which L_x is to be calculated, and D_0 is the given distance at L_0 is measured (Brown et al., 1990). This gives a distance of 5 miles for highway noise to attenuate to background levels.

Biodiversity, the relative complexity of an ecosystem or region as measured by the number of native species it supports, is important to long-term ecosystem function (U.S. Forest Service, 1999; McKnight, 2000). Human activities that decrease biodiversity, by eliminating sensitive native species, impair the associated ecosystems (U.S. Forest Service, 1999; McKnight, 2000). The U.S. Forest Service (1999) hypothesized that "measures of biodiversity provide the best integrative assessment of the effects of roads on ecosystems." A synthetic review distinguished three aspects of road effects on biodiversity (U.S. Forest Service, 1999):

- “Road density: As road density increases, thresholds may be passed that cause some species to go locally extinct. The probability of extinction depends, in part, on body size, with larger animals requiring larger residual populations to prevent their becoming extinct.
- “Road location: Roads in otherwise large natural patches of vegetation, riparian areas, and major wildlife corridors, and with rare habitats and species, have greater effects than roads not in such areas.
- “Road-effect zone: Roads can have effects over some distance from their centers so that their effective width can be many times their actual width.”

A secondary effect of roads is the conversion of nearby land to residential and commercial development. By providing infrastructure, it makes development easier, and facilitates economic activity and access. Bockstael (1996) found that commuting distances and distances to highways were significant variables in predicting residential development in the Patuxent watershed. A model by Bell and Bockstael (1997) had similar results for Howard County. Bell and Bockstael (1997) cited road improvements as partly responsible for increasing growth in western Howard County. New housing and commercial development in turn drives further road construction, and further sprawl.

MANAGEMENT IMPLICATIONS

Noss (1992) listed four fundamental objectives necessary to maintain the native biodiversity of a region in perpetuity:

1. Represent, in a system of protected areas, all native ecosystem types and seral stages across their natural range of variation.
2. Maintain viable populations of all native species in natural patterns of abundance and distribution.
3. Maintain ecological and evolutionary processes, such as disturbance regimes, hydrological processes, nutrient cycles, and biotic interactions, including predation.
4. Design and manage the system to be responsive to short-term and long-term environmental change and to maintain the evolutionary potential of lineages.

These objectives in mind, it is clear from the studies cited earlier that the most effective ecological management plan for a fragmented region like Maryland is to establish a system of large, contiguous habitat blocks serving as bioreserves ("hubs" or "core areas"), connected by corridors that allow successful dispersal between them. Different levels of ecosystem hierarchy should be considered (Harris, 1993). The main priority of conservation efforts should be preservation and restoration of breeding habitats. Increasing the quality of non-breeding habitat is also important. All ecosystem types and native species should be represented. Corridors should be strategically located, continuous, sufficiently wide, and with favorable abiotic and biotic composition, to allow successful dispersal of animals and seeds. It is at landscape and regional scales that connectivity is particularly important for conservation (Bennett, 1998). Besides maintaining populations of native species, hubs and corridors can protect water quality and soil, recharge aquifers, abate peak flooding, maintain stream baseflow, provide human recreation opportunities, and many other benefits.

Delorme (1998) states, "a natural heritage system attempts to enhance and protect ecosystem structure and function by protecting representative natural areas... Such a system involves identifying natural areas of local or regional significance as nodes or core areas that may be joined through natural or enhanced linkages or corridors." Robinson (1988) recommended managing for native habitat specialists. Areas with a high diversity of habitat specialists, and containing key microhabitats like streams and steep slopes, should be set aside as "natural areas", while areas with few habitat specialists could be managed for other purposes (Robinson, 1988). The Baltimore County greenway plan (Baltimore County Department of Environmental Protection and Resource Management, 1996) gave highest priority to preserving large forest patches with low edge-to-interior ratios, and delineated corridors between them based on satellite data. Harris (1984) recommended a system of old-growth "islands" in the Pacific Northwest, of varying size, surrounded by buffers of long-rotation forest. He proposed that the "islands" vary in size from 62 ac to 1235 ac, with a log-normal size-frequency distribution, and connected in a dendritic pattern by riparian corridors (Harris, 1984). The Southern Appalachian Forest Coalition (1998) proposed maintaining natural ecosystems and viable populations of all native species in the southern Appalachian mountains, by conserving large, high quality core habitats, connecting these with riparian or roadless corridors, supplementing these with buffer areas, and targeting barriers to ecological processes and functions in the conservation areas for restoration or mitigation. Harris (1988) lists examples throughout the Americas where corridors and “stepping stone” habitat islands have been set aside for wildlife habitat and migration. Finally, reserve systems should consider the long-term movement of sessile and non-sessile organisms and communities, changes in climate and ecosystems, and evolution of species (Harris, 1984; 1993).

Noss (1992) listed six guidelines to follow when designing a biological reserve system:

1. Species well distributed across their native range are less susceptible to extinction than species confined to small portions of their range.
2. Large blocks of habitat, containing large populations of a target species, are superior to small blocks of habitat containing small populations.
3. Blocks of habitat close together are better than blocks far apart.
4. Habitat in contiguous blocks is better than fragmented habitat.
5. Interconnected blocks of habitat are better than isolated blocks; corridors or linkages function better when habitat within them resembles that preferred by target species.
6. Blocks of habitat that are roadless or otherwise inaccessible to humans are better than roaded and accessible habitat blocks.

METHODOLOGY

OVERVIEW

The Green Infrastructure Assessment carried out by the Department of Natural Resources began with an evaluation of ecological data available for Maryland and its relationship to the important parameters described in the literature cited in the preceding chapter. Baltimore County's modeling work (see Baltimore County Department of Environmental Protection and Resource Management, 1996) and its results were also reviewed in detail; the model subsequently developed to assess Maryland's statewide green infrastructure was derived in part from this work. The statewide model methodology and output was reviewed by scientists at DNR; other state, federal and local agencies; universities; non-profit organizations like The Nature Conservancy; and consulting companies like Versar and ERM. Comments were used to revise the model. The model and the maps that resulted from its application were reviewed in a number of regional forums for local government planners and parks and recreation personnel, and corrected on the basis of information provided during this review. Hubs and corridors were evaluated for their ecological importance and for their relative vulnerability to conversion to developed uses. Finally a very fine-grained analysis was developed to help evaluate the relative importance of properties within the hubs and corridors of the green infrastructure.

Need for a Green Infrastructure focus

A Green Infrastructure training program coordinated by the U.S. Forest Service provided the following problem statement (unpublished):

> "Conservation today suffers from a tyranny of specialization -- the death from a thousand cuts. Most conservation efforts in this country are still reactive not proactive; haphazard not systematic; piecemeal not holistic; single purpose not multifunctional; too focused on the local or project-level scale and not enough on the watershed, regional or landscape scales critical to understanding the environmental context. We seem to dwell on individual pieces of the land development-land conservation puzzle and fail to take advantage of the strategic linkages between resources, tools, programs and people. Conservation efforts too often result in protected 'islands' too isolated to deliver their promise."

While Maryland's Greenways Program has attempted to address many of the issues noted in the above statement, it was felt by many that more emphasis on an ecological network was warranted. The Green Infrastructure network attempts to identify the best remaining ecological lands in Maryland as well as potential restoration areas. The purpose of this work is to:

- Systematically identify and protect ecologically important lands;
- Address problems of forest fragmentation, habitat degradation and water quality;

- Emphasize the role of a given place as part of a larger interconnected ecological system;
- Consider natural resource and ecosystem integrity in the context of existing and potential human impacts to the landscape;
- Maximize the influence and effectiveness of public and private conservation investments;
- Promote shared responsibilities for land conservation between public and private sectors; and,
- Guide and encourage compatible uses and land management practices.

Study area

The Green Infrastructure assessment was carried out within the state of Maryland, plus adjacent land up to the nearest paved road or major river in neighboring states. In western Maryland, the state boundary, which is not necesarily a natural boundary, was used where blocks of forest extended far into Pennsylvania, but not far into Maryland.

Maryland ranges from the Atlantic Ocean to the Appalachian Mountains, spanning five physiographic regions (Coastal Plain, Piedmont, Blue Ridge, Ridge and Valley, and Appalachian Plateau). Each region is defined by unique geology and varying climate, and thus different assemblages of flora. Maryland is important geographically, at the southern extent of many northern plant and animal species, and at the northern extent of many southern plant and animal species (Williams, 1991).

Network design overview

The concept underlying Green Infrastructure protection is to link large, contiguous blocks of ecologically significant natural areas (hubs) with natural corridors that create an interconnecting network of natural lands across the landscape. Such connection can help to offset the functional losses caused by fragmentation.

The first step of this assessment was a review of pertinent ecological and environmental planning literature, and collection of relevant data. Some findings from the literature are summarized above in the Background section. Much of the data we used is listed in Appendix A. We were limited to data that could be placed in a Geographic Information System (GIS), such as satellite-derived land cover and elevation, locations of roads and streams, and ground-sampled animal and plant locations. Furthermore, for consistency, we considered only data available statewide. Some counties had created more accurate maps of streams, floodplains, etc. than those covering the entire state, but using these would have spatially biased the analyses.

Based on a review of the literature and available data, we performed a coarse-filter landscape analysis, striving to include a full range of ecosystem elements. This initial analysis, described in Weber and Wolf (2000), used GIS data to identify an interconnected network of hubs and corridors at a resolution of about 120 feet. Within the network, areas were evaluated and ranked within their physiographic region for a variety of ecological and development risk parameters, as well as composites of these. These relative rankings were done at two different scales: by individual hub or corridor, and by individual cell (about a third of an acre). The goal was to identify those areas most important ecologically, and most at risk of loss to development. From these spatial models, maps were created of both the entire network within a given region, and conservation priorities within the network.

The initial model's methodology and map output were reviewed by numerous scientists and planners both within and outside DNR, over about a one year period. Based on their recommendations and further literature reviews, the model was revised. Methodologies were also discussed with scientists and planners working on similar projects, such as the Florida Greenways Project, recently published in University of Florida Geo-Facilities Planning and Information Research Center (1999) and in Hoctor et al (2000).

The revised Green Infrastructure model, described in more detail in subsequent sections and appendices, was also reviewed by scientists and planners within and outside DNR. Furthermore, areas were added or subtracted based on comments from county planners. The maps published in Maryland Greenways Commission (2000) are a result of this revised model and county feedback.

As before, areas within the revised network were evaluated and ranked within their physiographic region for a variety of ecological and development risk parameters, as well as composites of these. These relative rankings were again done at two different scales: by individual hub or corridor, and by individual cell. Furthermore, gaps, which are areas of agriculture, mining, or other human land uses within the ecological network, were evaluated for their restoration potential. These evaluations are discussed in greater detail in the following sections.

The Green Infrastructure model and maps will continue to be revised based on the best available data. Because the computations are time-consuming, and because validation reviews are necessary, it is not projected that updates will occur more frequently than once every 3-5 years. The next phase, already begun for parts of the eastern shore, is a photographic and field validation of Green Infrastructure maps. More detailed field surveys will be required before specific conservation or restoration action is taken, such as purchasing properties or development rights, or restoring lost wetlands.

IDENTIFICATION PHASE

Identify hubs

Hubs in the Green Infrastructure network represent the most important large ecological patches remaining in Maryland. Maintaining them as open space and being careful about what sort of development happens around them are vital to retaining the state's biological diversity in the face of continued human colonization of the landscape. Hubs are areas critical to particular species and/or to particular life stages of multiple species - interior forest, for example, is essential for nesting success for many species of songbirds, while sensitive species areas represent the presence of one or more rare, threatened or endangered species of plant or animal or other unique natural community. Large blocks of contiguous forest are necessary, too, to support forestry as a continuing, and regionally very important, economic activity.

Hubs contain one or more of the following:

- areas containing sensitive plant or animal species;
- large blocks of contiguous interior forest (at least 250 contiguous acres, plus the 300 foot transition zone);
- wetland complexes with at least 250 acres of unmodified wetlands;
- streams or rivers with aquatic species of concern, rare coldwater or blackwater ecosystems, or important to anadromous fish, and associated riparian forest and wetlands; and
- conservation areas already protected by public (primarily DNR or the federal government) and private organizations like The Nature Conservancy or Maryland Ornithological Society.

In the model, the above features were identified from GIS data (see Appendices), and combined. Intensive human land uses (development, agriculture, and quarries) and major roads were excluded, natural areas less than 100 contiguous acres were dropped, adjacent forest and wetland was added to the remaining hubs, and the edges were smoothed to eliminate narrow tendrils.

Finally, buffers were added around potential migration paths, wetlands, streams, and shorelines within hubs. This extended the boundaries of hubs up to 550 feet in some places. Many of these extensions contain agriculture or other intensive human land uses, and would benefit from restoration. For mapping purposes, these buffers were added to their associated hubs.

Link hubs with corridors

Corridors in the Green Infrastructure network are linear features, at least 1,100 feet wide, linking hubs together to allow animal and plant propagule movement between hubs. The hope behind maintaining this pattern is that there will be enough populations of species in the discrete hubs within a region that any localized extinction will be offset by movement between hubs, with recolonization of the hub that experienced the extinction. The corridors delineated in many cases follow prominent features like streams or ridges. In other locations they may be less intuitive, based rather on remaining pathways of upland natural vegetation in a landscape dominated by human modification. An effort was made to avoid roads and urban areas in the methodology used to identify possible corridors. To function effectively, corridors should be wide enough to provide interior conditions for habitat specialists (favorable microclimate, protection from edge predators and invasive exotics, etc.), as well as protecting the hydrology and water quality of contained streams and wetlands.

Corridor identification and delineation (see Appendix A for details) was based on many sets of data, including land cover/land use, wetlands, roads, streams, slope, floodplains, Maryland Biological Stream Survey (MBSS) aquatic resource data, and fish blockages. Linkages were tailored to three different ecotypes: terrestrial, wetland, and aquatic. For each of these ecotypes, core areas were identified within hubs, and a "corridor suitability" layer based on land cover, stream, riparian width, aquatic community condition, road, slope, and land management "impedance" to animal and plant propagule movement was created. Impedance, which is the inverse of suitability, measures the degree to which the landscape parameter inhibits wildlife use and movement. For example, urban land cover has a much higher impedance than forest. After creating a composite impedance or suitability layer for each ecotype, we used a GIS technique called least-cost path analysis to determine the best ecological paths between core areas, and thus, hubs.

In general, corridor preference, based on literature reviews, was given to streams with wide riparian buffers and healthy aquatic conditions. Other good wildlife corridors included ridge lines, valleys, and forest. Urban areas, roads, and other unsuitable features were avoided. Since Maryland historically was dominated by forest, the terrestrial connections linked large areas of interior upland forest within hubs. Wetland linkages were between wetlands of special state concern (WSSC) or large, unmodified wetlands within hubs. These core wetlands were best linked by natural waterways and wetlands. Salt marshes were also linked by estuaries and bays, which were not included explicitly in the analysis. Core areas for fresh-water aquatic communities were lakes and rivers, or streams with high biotic integrity, within hubs determined previously. These were best linked by natural waterways with riparian forest cover or adjacent wetlands, and without fish blockages.

The corridors identified by the least-cost path analysis were then assigned a width according to the neighboring topography and land cover. Where corridors followed streams, we buffered streams 550 feet on each side. Thus, the corridor would contain 500 feet of interior conditions along its path, and 300 feet of edge transition on either side. If the floodplain exceeded this distance, the corridor was defined by the 100-year floodplain, up to a maximum of 1000 ft from the stream; or by ridge-to-ridge distance. Where corridors were not along streams, we buffered the least-cost path a distance of 550 feet. The width of corridors was then extended to account for compatible landscape features, such as adjacent forest or wetlands. “Nodes” were defined as patches of interior forest, plus their edge transition; unmodified wetlands, with an upland buffer; sensitive species areas; or protected areas along linkages between hubs. Only natural cover was included. Nodes serve as “stepping stones” or “rest stops” for wildlife movement along corridors, making successful crossings between hubs more likely. For mapping purposes, nodes were added to their associated corridors.

County feedback

Maps of Green Infrastructure model output were reviewed by county planning and parks and recreation departments. Several dozen areas were suggested as additional inclusions, as either hubs or corridors. In most cases, these were county parks or other public lands missed by the model. If these areas contained at least 100 ac of contiguous natural area (forest, wetland, beach, etc.), or if they were adjacent to modeled hubs or corridors, they were added to the proposed network. Otherwise, they were not added. Other additions included stream or river valleys being targeted by counties for conservation and/or restoration, such as Watts Branch, Southwest Branch, Winters Run, Little Bennett Creek, Deer Creek, and the Monocacy River. Some riparian corridors were adjusted to retain entire stream valleys. For example, Deer Creek was buffered along its entire mainstem, amending the modeled corridor which jumped out of the riparian zone where the river passed through agriculture. Additions stemming from county comments totalled 34,947 acres (an increase of 1.32%).

Conversely, several areas were suggested for deletion. Most of these were areas that had been developed since the model source data was acquired. In a few other cases, proposed corridors were too heavily parcelized for feasible implementation, and alternative routes which were more protected were suggested. ADC street maps were also referenced to omit unfeasible corridors. Most of the 23 subtractions were in the fast-growing central and southern portions of the state. 9086 acres (0.34%) were subtracted from the model.

Further additions came from the Baltimore County greenway model (see Baltimore County Department of Environmental Protection and Resource Management, 1996). Areas identified as hubs or corridors by this model, as natural areas according to both MRLC and OP 1997 land use/land cover, and not identified by the Green Infrastructure model, were added to the proposed network. These additions were relatively minor (3,553 additional acres, or 0.13%).

Finally, ecologically significant areas digitized by the Maryland DNR Heritage Division were added if they were adjacent to, but not entirely within, modeled hubs or corridors. These included Natural Heritage Areas (NHA), Wetlands of Special State Concern (WSSC) and 550 ft buffers, Habitat Protection Areas (HPA), Ecologically Significant Areas (ESA), and Geographic Areas of Particular Concern (GAPC). The ESA's, HPA's, and GAPC's were draft products at the time. Furthermore, not all areas containing observed rare species had been digitized (except the rough delineations of SSPRA's). The heritage areas totalled 189,798 acres, although some of these were buffers. 172,593 acres (91%) fell within GI hubs or corridors. Of the remainder, 11,649 acres (68%) were added to the proposed network, bringing the total to 184,242 acres (97%). The increase in GI area was 0.44%; some of this overlapped with additions from other sources. Heritage areas falling outside the network should still be considered for protection.

Maps containing these revisions were mailed to the planning departments of each county for further review. The final product was published in Maryland Greenways Commission, 2000. The Green Infrastructure network published in this atlas was 43,604 acres (1.65%) larger than the model.

Model verification using aerial photographs and expert knowledge

Implementation of the Green Infrastructure Assessment should be preceded by photographic and field assessment. Because of limitations in data resolution, maps of model output are only meaningful at a 1:100,000 scale or smaller. Acquisition dates varied between 1980 and 1997, mostly between 1991-97. Thus, conditions could have changed on the ground. Green Infrastructure model results have been reviewed by state and county biologists and planners, and will continue to be. Hubs and corridors in much of Maryland's eastern shore were compared to high-altitude aerial photographs (Digital Orthophoto Quarter-Quads; DOQQ's), and were found to agree in most cases. DOQQ's are produced by the U.S. Geological Survey at approximately 1 meter ground resolution. In a few cases, alternative corridor routes were suggested by the photos. This information currently resides as notes on a hardcopy map, but will be converted to digital format. During the next year, this will be done for the entire state.

Field assessment and verification

Areas prioritized for immediate conservation or restoration action should be field verified. For site-specific planning, they should also be mapped at a finer resolution than the Green Infrastructure model. This can be done using aerial photographs and property boundaries.

Given sufficient time and resources, the entire network can be systematically verified. A rapid field assessment for forests was described in Baltimore County Department of Environmental Protection and Resource Management (1996). A study conducted by the Smithsonian Institute and the Nature Conservancy in the Nanticoke watershed is leading to a regional wetland evaluation manual. And the Maryland Biological Stream Survey (MBSS) has published stream sampling and monitoring manuals (Maryland Biological Stream Survey 2000a, 2000b). Sayre et al (1999) describes a detailed approach for assessing biodiversity in a rapid and integrative manner. Rapid Ecological Assessment (REA) is a methodology developed by The Nature Conservancy to provide comprehensive and reliable information about biodiversity resources in situations where time and financial resources are limited (Sayre et al, 1999). REAs combine remotely-sensed imagery, reconnaissance overflights, field data collection, and spatial information visualization to generate useful information for conservation planning (Sayre et al, 1999). These provide a useful starting point.

Rapid field assessment of high priority hubs and corridors will begin in summer 2001. A major emphasis will be ensuring that existing digital data has not been superceded by recent development, and to assess ecosystem condition. For example, how old and diverse are the plant communities? Are the streams ditched or channelized? Are the streams impaired by "flashy" hydrology, sedimentation, or pollution? Are the wetlands functionally impaired by ditching, filling, or other sources of disturbance? Are there invasive exotic species present? Many areas have already been surveyed for other purposes, and this information can prove a useful guide. Detailed field surveys are preferable, but these are generally expensive and time-consuming.

Data from ground surveys can be combined non-parametrically, as the GIS ranking of hubs and corridors; or standardized, weighted, and combined (as in HGM wetland assessment or in Baltimore County Department of Environmental Protection and Resource Management (1996)). Areas ranking high in the landscape-scale GIS assessment, but low on the ground, should be given lower priority for conservation than areas ranking high in both categories.

ANALYSIS PHASE–ECOLOGICAL RANKING

Rankings of both hubs and corridors were carried out within the four physiographic regions in this analysis, both because natural conditions and communities vary widely between the Coastal Plain and the Appalachian mountains, and to ensure ecosystems adapted to different climates and substrates were represented in the top ranking hubs.

Rank hubs by relative ecological importance within physiographic regions

Hubs, which were separated by major roads and/or intervening human land uses, were evaluated and ranked within their physiographic region for a variety of ecological parameters. To derive a composite ecological ranking, the rankings for 29 parameters were multiplied by an importance weighting, and added together for each hub. Parameters (see Table 3) were chosen and weighted according to feedback from biologists and natural resource managers; literature reviews; minimization of redundancy, area dependence, and spatial overlap; balancing different ecotypes; data reliability; and examination of output from different combinations. To assist in the evaluation of corridors that link hubs (see next section) the hubs were then divided into three tiers by their composite ecological score: tier 1 comprised the top 33% of hubs; tier 2, the middle 33%; and tier 3, the bottom 33%. The ranking system also may be used to help prioritize conservation efforts. (The percentile breakout may be adjusted for other purposes as necessary.)

Table 3. Parameters and weights used to rank overall ecological significance of each hub within its physiographic region.

Parameter	Weight
Proportion of internal gaps	4
Area of upland Natural Heritage Areas (NHA)	5
Area of WSSC and wetland or aquatic NHA	5
Area of upland interior forest	4
Area of wetland interior forest	4
Area of other wetlands	3
Length of streams within interior forest	4
Number of stream nodes (sources and junctions)	2
Fish index of biotic integrity (IBI) score	1
Benthic invertebrate IBI score	1
Aquatic species of concern	2

Parameter	Weight
Presence of brook trout	1
Anadromous fish index	1
Sensitive Species Project Review Areas (SSPRA) area	2
Presence of SSPRA or aquatic species of concern	2
Percent upland forest that is deciduous or mixed	4
Standard deviation of elevation	1
Number of different NWI wetland types	1
Number of different natural soil groups	1
Number of different physiographic regions	1
Mean distance to the nearest primary or secondary road	3
Density of interstate, state, and county roads	3
Area of highly erodible soils	2
Area of proximity zone outside hub	2
Nearest neighboring hub distance	3
Shape index	1
Surrounding buffer suitability (within 300 ft of hub)	1
Interior forest within 10 km of hub periphery	1
Marsh within 10 km of hub periphery	1

Rank corridor segments by relative ecological importance within their physiographic provinces

Corridors were also evaluated and ranked within their physiographic region for a variety of ecological parameters (Table 4). There were two tiers of corridors. The top tier of corridors connected the top tier hubs (those with composite ecological scores ranking in the top third of hubs in their physiographic region). The second tier of corridors connected the middle and lower tier hubs (those with composite ecological scores ranking in the lower two-thirds of hubs in their physiographic region).

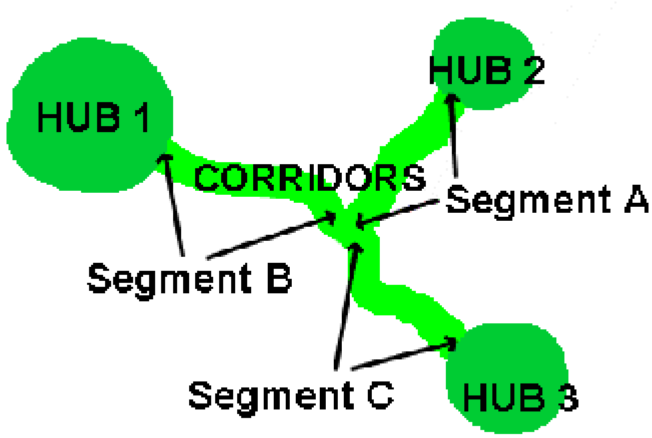

Figure 1. Separation of corridors into segments for analysis.

Because corridors often intersected, they were seperated into segments for comparative analysis (see Figure 1). A corridor segment was defined as that stretch of a corridor that terminated at either a hub or an intersection with another corridor.

Table 4. Parameters and weights used to rank overall ecological significance of each corridor segment within its physiographic region.

Parameter	Weight
Does corridor link hubs in top ecological tier?	2
Ecological ranking of hubs connected by corridor	4
Variety of ecotypes connected (terrestrial, aquatic, wetland)	2
Segment area (indirect measure of length)	1
Node area along corridor segment	2
Number of corridor breaks	4
Number of primary road crossings	4
Number of secondary road crossings	2
Number of county road crossings	1
Number of railroad crossings	1
Proportion of gap area in corridor segment	4
Percent of gap area in corridor segment	4
Buffer suitability within 300 ft of corridor	2

We then separated corridor segments into two size groupings, because shorter corridors are less likely to contain roads or other breaks. Corridor segments ranged from <1 to 2971 ac. After examining distribution of the data, we grouped them into either “short” (<100 ac; about 3/4 mile or shorter), or “long” ($100 ac). Corridor segments were then ranked from best to worst for each parameter in Table 4, within their physiographic region and size class. To derive a composite ecological ranking, the rankings for the 13 parameters were multiplied by an importance weighting, and added together for each corridor segment.

The ecological rankings of corridor segments can help compare alternative linkages between hubs. One can average the rankings (when converted to percentiles) of corridor segments along a particular pathway, or note the segment with the lowest score. For example, if the segments along pathway A between hub #1 and hub #2 rank lower than those along pathway B between the same hubs, then pathway B would be a more viable linkage. Pathway A may have more breaks along its route, more road crossings, or less natural land cover.

ANALYSIS PHASE–VULNERABILITY RANKING

In order to help focus expenditure of available funds, it is helpful to look at where green infrastructure lands are most vulnerable to conversion to non-resource use. This need was reflected in amendments to the Program Open Space law in the 1990's. Methodology to assess development pressure on lands in particular locations is evolving; following the approach used in the ecological ranking of hubs and corridors, our vulnerability ranking also was done for each physiographic province.

Level of protection from development

The following ownerships, easements, state regulations, and state incentives were identified as helping protect natural areas from development, to one degree or another. We lacked spatial data on all such mechanisms, so this analysis will be updated when such information is available. County-specific conservation measures were not included, but this also will be added in the future. Furthermore, it is anticipated that over time, protected lands will increase, and regulations will change.

- Public and privately owned conservation lands: These are essentially protected from development, although management practices differ.
- Other publically owned lands: These include county parks, military lands, etc., which are not managed for conservation. Private development may be discouraged here, although public development (ballfields, runaways, etc.) is not necessarily restricted.
- Conservation easements: These are perpetual easements on development, although they do not prevent management practices such as clearing forest for agriculture. MET conservation easements protect farmland, woodland, wetland, natural areas, scenic open space, and historic sites.
- Agricultural easements: These are long-term easements (in practice, perpetual) on development, although they do not prevent management practices such as clearing forest for agriculture. They preserve Maryland farmland, by restricting use of land only to agricultural use.
- Wetlands: Wetlands require permits to disturb extensively enough for development. WSSC are also given a 100 foot buffer from development.
- Steep slopes ($25%): Steep slopes require permits to develop on, as well as being difficult from an engineering standpoint.
- SSPRA: SSPRA provide little protection against development; only environmental reviews.
- CBCAC resource conservation areas: Resource conservation areas defined by the Chesapeake Bay Critical Area Commission are within 1000 feet landward of the state tidal wetlands boundary of the shoreline of the Chesapeake Bay and its tributaries, and are nature-dominated environments such as wetlands, forests and abandoned fields or areas of resource utilization activities such as agriculture, forestry, fisheries or aquaculture. They are also defined as areas where density is less than one dwelling unit per five acres; or areas with dominant land uses in agriculture, wetland, forest, barren land surface water, or open space. Digital layers were only available for 3 counties, so this parameter was not used.
- Outside Priority Funding Areas: Under Smart Growth legislation, state funding for projects in Maryland municipalities, other existing communities, industrial areas, and planned growth areas

designated by counties will receive priority funding over other projects. Priority Funding Areas are locations where the State and local governments want to target their efforts to encourage and support economic development and new growth. These boundaries will limit development only indirectly, since only state funding is involved.

- Inside Rural Legacy Area: The Rural Legacy Program directs State funds into a focused and dedicated land preservation program specifically designed to limit the adverse impacts of sprawl on agricultural lands and natural resources. The Program allocates State funds to purchase conservation easements for large contiguous tracts of agricultural, forest and natural areas subject to development pressure, and fee interests in open space where public access and use is needed. Local governments and private land trusts are encouraged to identify Rural Legacy Areas and to competitively apply for funds to complement existing land conservation efforts or create new ones. Rural Legacy Areas have more effect on development than PFA's, since county governments tend to zone these areas for agricultural and natural resource conservation.

To derive a composite score, restrictions on development were given a score between 0 and 1 for each mechanism, with 0 being the most restrictive (no development permitted), and 1 being the least restrictive (no restrictions on development). Scores (Table 5) were solicited from permitting experts. The restrictions are multiplied together; for example, a wetland falling within a SSPRA and Critical Area boundary would contain the restrictions of all three designations. Both hubs and corridor segments were analyzed for their current level of protection.

Table 5. Restrictions on development, and their relative strength (a score between 0 and 1)

DATA LAYER	RESTRICTION SCORE
Public and privately owned conservation lands	0.0
Other public ownership	0.5
Conservation easements	0.0
Agricultural easements	0.0
Wetlands	0.2
Slopes >=25%	0.2
SSPRA	0.9
CBCAC resource conservation areas	0.9
Outside Priority Funding Areas	0.9
Inside Rural Legacy Area	0.7

Rank hubs by relative risk of development within physiographic provinces

Within each physiographic region, hubs were also ranked from highest to lowest for the development risk parameters listed in Table 6. These rankings were combined linearly like the ecological rankings. All hubs are considered ecologically important, but initial conservation efforts might be directed toward those at the greatest risk of loss to development. A hub's risk of development can be combined with its ecological score to help prioritize efforts. Hubs ranking in both the top quantile (e.g., top 10-20%) of their physiographic region ecologically, and the top quantile threatened by development, should be candidates for immediate action. If field surveys verify the importance of these areas, conservation measures should take place before they are lost forever. The development risk analysis is currently being revised; this is described in a later section.

Table 6. Parameters and weights used to rank overall development risk of each hub within its physiographic region.

Parameter	Weight
Level of current protection from development	**4**
Percent of hub managed primarily for natural values (GAP Management Status 1 or 2)	**2**
Mean development pressure, as calculated by Maryland Dept. of Planning	**2**
Proximity to commercial, industrial, or institutional land use	**1**
Mean distance to DC beltway	**1**
Cost of land (at county scale)	**1**
Mean distance to nearest interstate, primary state, secondary state, or county road	**1**

Rank corridor segments by relative risk of development within their physiographic provinces.

Corridor segments were ranked using the same development risk parameters as hubs (Table 5). Corridors tend to cross more private land parcels than hubs, and may be at greater risk of development. This is especially true because loss of part of the corridor, if the break is significant, destroys the effectiveness of the entire linkage. One potential solution is to focus corridor protection more on development set-asides, eco-friendly design, or easements, than on land acquisition. The latter may be more effective and appropriate for hubs.

ANALYSIS PHASE–FINE SCALE RANKING

In order to help compare particular pieces of land that might be protected under the GreenPrint program, it is helpful to be able to assess relative ecological value at a much finer scale than whole hubs or corridors. Importance of the hub or corridor in which the particular project area is located plays a role in this finer-grained assessment.

Rank individual cells by relative ecological importance

The Maryland landscape was also analyzed at a finer scale, to allow a more detailed site comparison and prioritization. Individual “grid cells” are pixels determined by the resolution of the satellite imagery we used (Landsat Thematic Mapper). The cells are squares corresponding to an area of 0.314 acres. The cell rank is based on both its local significance and its landscape context. Part of the cell ecological rank is the rank of the landscape feature in the Green Infrastructure network (i.e., whether it falls within a hub or corridor, and the relative ecological importance of that component; see Table 7), and part of the cell rank is based on local features (e.g., proximity to streams or rare species habitat; see Table 8).

Table 7. Weighting of landscape feature used to assess ecological value of individual cells. Weights vary between 0 and 10.

Landscape feature	Weighting
Hubs	5-10, depending on ecological rank within physiographic region
Top tier corridors	7
Lower tier corridors	4
Nodes	3
Internal hub gaps	2
External buffers	2
Not in Green Infrastructure network	0

Table 8. List of local features and their relative weighting used to assess ecological value of individual cells.

Parameter values vary between 0 and 10, and were then multiplied by the parameter weight.

Parameter	Weighting
Land cover	4
Distance to nearest road	4

Parameter	Weighting
Highly erodible soils	2
Proximity to unmodified wetlands	4
Wetland interior forest (note: weighting is lower because these areas are also included as wetlands)	2
Upland interior forest, except pine in Piedmont, Coastal Plain, and Blue Ridge provinces	4
Upland interior forest, pine in Piedmont, Coastal Plain, and Blue Ridge provinces	2
Proximity to heritage areas	6
Inside other SSPRA	2
Proximity to high integrity streams	6
Proximity to low integrity streams	2
Proximity to other streams or in 100 year floodplain	4
Proximity to stream nodes	1

We combined the weighted local parameter values for each grid cell, and scaled this sum between 0 and 100 within each physiographic region, thus giving each cell a percentile of the regional high score. To reduce the effect of outliers, the high score was the lower bound of the top ranking hectare within the physiographic region.

Next, we combined the local and landscape scores. We placed both on a scale between 0 and 100 (i.e., multiplied the landscape context score by 10), and then compared different local vs. landscape weightings to field data and expert knowledge (Table 9). The final grid cell score was based 55% on local conditions, and 45% on its landscape context.

Table 9. Evaluation of grid cell ecological values given different combinations of landscape and local parameters.

Weighting of landscape feature	Weighting of local conditions	Evaluation of model output
100	0	No resolution of local-scale differences.
55	45	Insufficient resolution within hub and corridor network.
50	50	Connections are more apparent than 45/55 and 40/60 weightings, but provides less resolution.
45	55	Same areas are targeted as significant as with 50/50 weighting, but resolution within these areas is better. For local targeting, this is probably the best weighting combination, especially where hubs are large and contain a greater gradient of environmental conditions.
40	60	Connections and groupings are less apparent.
0	100	No consideration of the larger landscape context.

One of the uses of cell-based ecological ranking was to evaluate individual parcels. For example, we averaged the cell ecological scores within each Chesapeake Forest tract to help decide which tracts would be targeted for conservation, and which would be targeted for sustainable forestry. Other information was used in conjunction with this assessment, such as rare species locations; stand composition, age, and preparation; and proximity to existing DNR lands.

RE-RANKING OF HUBS AND CORRIDORS

The hub and corridor ecological and development risk rankings described in the preceding section were initially completed before the county review process. Thus, we had to recompute them for the revised network. We also examined hub areas along the Delaware-Maryland border identified by a landscape model tailored for the entire Delmarva (the Delmarva Conservation Network - DCN), but not identified by the Maryland Green Infrastructure (GI) model. The Delmarva model used different data and criteria, based on its multistate context. Additions from the DCN model were more significant for interstate corridors than for border hubs. These model discrepancies were compared to aerial photographs, and if indeed natural cover, were added to the Green Infrastructure.

We also added estuarine marsh along the Coastal Bays identified by the DCN model but not the GI model. These wetlands were partially drained by human activities, but nevertheless identified by Tiner et al (2000) as having high potential for fish, shellfish, and waterbird habitat. They also had high potential for nutrient transformation, sediment and other particulate retention, coastal storm surge detention, and shoreline stabilization (Tiner et al, 2000).

Re-rank hubs by relative ecological importance

New data used to evaluate and rank hubs included specific locations, global and state rarity, and population viability of rare plants and animals; and vegetation alliances from the Mid-Atlantic Gap Analysis Project (see Scott et al, 1993; National Gap Analysis Program, 1994). The revised list of ecological ranking parameters is listed in Table 10.

Table 10. Revised list of ecological parameters used to compare hubs within their physiographic region.

Parameter
Occurrences of rare, threatened and endangered plants and animals, weighted by their global rarity, state rarity, and population viability
Area of Delmarva fox squirrel habitat
Fraction of hub in natural vegetation communities that are mature for site conditions (i.e., area that has been in a natural condition for a relatively long time)
Area of Natural Heritage Areas
Mean fish IBI score
Mean benthic invertebrate IBI score
Presence of brook trout
Anadromous fish index
Proportion of interior natural area in hub
Area of upland interior forest
Area of wetland interior forest
Area of other unmodified wetlands
Length of streams within interior forest
Number of stream sources and junctions
Number of GAP vegetation types
Topographic relief (standard deviation of elevation)

Parameter
Number of wetland types
Number of soil types
Number of physiographic regions in hub
Area of highly erodible soils
Remoteness from major roads
Area of proximity zone outside hub
Nearest neighboring hub distance
Patch shape
Surrounding buffer suitability
Interior forest within 10 km of hub periphery
Marsh within 10 km of hub periphery

As before, hubs were ranked within their physiographic region from best to worst for each parameter in Table 10. We calibrated these rankings by converting to percentiles (percentile = rank * 100 / max rank). We then multiplied the percentiles by the parameter's importance weighting, and summed these to derive a composite ecological rank. The importance weightings were a function of the parameter's utility and data reliability. Some parameters were area-dependent (e.g., acres of interior forest), some were area-independent (e.g., proportion of interior natural area), and some were inversely area-dependent (the larger the hub, the less important metrics of isolation are). Relative weightings were adjusted using different combinations, and resultant model output contrasted.

Re-rank hubs by relative risk of development

The hubs delineated for ecological re-ranking will also have their relative risk of development updated. This is currently incomplete, but will incorporate the parameters in Table 11. A composite risk of development rank will be computed for each hub, as was the composite ecological rank. The risk parameters are only applicable within Maryland.

Table 11. Revised list of development risk parameters used to compare hubs within their physiographic region.

Parameter	Importance
Level of current protection from development	High
Percent of hub managed primarily for natural values (GAP Management Status 1 or 2)	Medium
Projected forest and wetland loss by 12-digit watershed between 1997-2020, as calculated by Maryland Dept. of Planning. A finer	High

Parameter	Importance
spatial scale will be used if available.	
Area zoned by counties for development	Low
Mean approximate travel time to urban areas (inverse of road distance, weighted by road type), multiplied by the number of jobs or seasonally high population of the urban area (e.g., Ocean City has large number of transients during the summer).	Medium
Mean land value (the cheaper, the more at risk) at the parcel level	Medium
Number of land parcels in the hub	Low
Proximity to parks and waterfronts	Medium
Remoteness from other development	Low

Re-rank corridors

Corridors were also redefined by county comments and, in a few cases, by the DCN model. Corridor segments will be re-ranked for their relative ecological value and risk of development. This process is currently incomplete.

COST OF PURCHASING HUBS OR CORRIDORS

We interpolated a continuous land value surface from 1997-8 Maryland PropertyView parcel centroids, the parcels' unimproved full market land value, and their size in acres. We selected only parcels at least 10 acres. Since they could not be privately developed, areas currently owned by the public or with development easements, plus lakes, rivers, and bays, were subtracted. This left privately owned land without development easements. The interpolated land value of these areas was summed for each hub and corridor segment, to estimate the cost of purchasing them (as of 1997-8). When 2000 PropertyView data is available for all Maryland counties, this information will be updated. This model can help guide initial GreenPrint funds toward the most ecologically significant and most threatened areas, given a fixed budget.

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Appendix A
Green Infrastructure network model methodology

! **Define study area**

" Define the study area for the Green Infrastructure analysis: All Maryland, plus adjacent land up to nearest paved road in neighboring state or major river (i.e., Potomac). The state boundary is not necessarily a natural boundary. In Western MD, the state boundary was used where large blocks of forest extended far into PA but not far into MD.

" Set cell size to that of MRLC.

! **Identify hubs**

" Sensitive Species Project Review Areas (SSPRA)

- Converted SSPRA polygon layer (see *sspra.txt*) to Boolean grid
- Subtract Chesapeake Bay, Chincoteague Bay and Atlantic Ocean open water

" Large blocks of contiguous interior forest

- Create land cover grid from Maryland_land_cover_v99-01(see *maryland_readme_ver9901.txt*) within the state and MRLC, v3 (see *readme_reg3_040998.txt*) outside the state.
- Create forest grid from land cover grid
  # Combine classes 41, 42, 43, and 91 (Deciduous forest, Evergreen forest, Mixed forest, Woody wetlands)
  # Outside MD, use MRLC forest cover. In MD, use areas classed as forest in both MRLC and OP97, and areas classified as forested wetland in MRLC (OP LU does not separate forested and nonforested wetlands). MRLC may miss large lot subdivisions, orchards, brush, and recent land use changes.
- Bisect forest grid with interstate, state, and county roads

- MD roads
    - Query MD road coverage (SHA state roads) to extract interstate, state, and county roads: `ArcView: Query ([Layer] = 'RD_ST_PRI') or ([Layer] = 'RD_ST_SEC') or ([Layer] = 'RD_INTST') or ([Layer] = 'RD_CNTY')`
- DE and VA roads
    - Selected TIGER DLG roads with CFCC = A00 to A38 for DE and VA in Delmarva.
- PA roads
    - Selected interstate, state, and township roads for PA counties bordering MD (select all [LGDS_LAYER] but 'OTHER_ROAD'). Source: Pennsylvania Spatial Data Access system (PASDA) FTP site (see D:\data\PA_data\rdx-bedford.htm for metadata).
- WV roads
    - Selected USGS DLG roads for WV bordering MD.
    - Removed trails and Class 5 roads (for 4-wheel drive).
- Merged MD, DE, VA, PA, and WV roads.
- Convert to Boolean grid
- Also created separate grids for primary roads, secondary roads, and county roads.
- Remove roadways from forest grid

\- Determine grid of interior forest

- Harris (1984), Brown et al (1990), and Kapos et al (1993) cite a distance of 2-3 tree heights from the forest edge to reduce the effects of sunlight and wind penetration. This translates to about 300 ft, and could be considered the abiotic transition zone. However, some forest interior birds nest further from the edge than this (Bushman and Therres, 1988). Further, Gates and Evans, in a study of brown-headed cowbirds in 1996, detected 94% of female breeding fixes within 220 m of forest edges. They defined interior forest as >=250 m (820 ft) from the edge. About 60% of telemetry fixes were within 50 m of the edge (Gates and Evans, 1996). Since females travel up to 10 km between breeding and feeding areas (avg was 2.3 km), they were abundant even in Western MD state parks (Gates and Evans, 1996).
- I chose the abiotic transition zone, or 300 feet, as more applicable to forest ecosystems as a whole.

- # Find distance from each woods cell to nearest non-woods cell. In ARC GRID, run euclidean distance function on non-woods grid. Convert distance grid to integer values to save disk space. A resolution finer than 1' exceeds map accuracy, so no resolution is lost.
- # Reclassed distances at least 300 feet from forest edge to a grid of interior forest.

- Select forest blocks with at least 250 ac of contiguous interior forest, based on 300 ft distance. According to Bushman and Therres (1988), 250 ac is the minimum forest size to maintain a viable breeding population of 7 forest interior birds of Maryland. 8 required smaller contiguous forest blocks, and 3 required more.

" Large wetland complexes

- First, identify wetlands from NWI.
- Removed NWI Systems/subsystems M1 (Marine Subtidal), E1 (Estuarine Subtidal), R1 (Riverine Subtidal), L1 (Lacustrine Limnetic), and U (Upland)
- Also removed E2 (estuarine intertidal) FL (mud flats), RF (reef), RS (rocky shore), and US (unconsolidated shore). Considered these aquatic.
- Removed all human-modified wetlands, as defined by NWI code Special Modifiers (d=partially drained or ditched, f=farmed, h=diked or impounded, r=artificial substrate, s=spoil, x=excavated)
- Defined buffer around wetlands
  - # Wetland buffers can perform the following functions (North Carolina State University, 1998):
    - * sediment removal and erosion control,
    - * nutrient transformation and removal,
    - * metals and other pollutant reduction,
    - * stormwater runoff reduction through infiltration,
    - * reduction of water temperature,
    - * reduction of human impacts by limiting easy access and by minimizing edge effects from noise, light, temperature, and other changes,
    - * protection for interior wetland species, and
    - * a barrier to invasion of nuisance and exotic species.

- # Wetland buffers can also protect against water table drawdown from adjacent ditches, and the wetland-upland ecotone is utilized by numerous species of wildlife (Brown et al, 1990).
- # The necessary buffer width will vary according to individual site by type of wetland, sensitivity to disturbance, intensity of adjacent land use, groundwater depth and hydraulic conductivity, proximity and characteristics of drainage ditches and other water control structures, slope and soil characteristics, species present, and buffer characteristics such as vegetation density and structural complexity, soil condition, etc. (Brown et al, 1990; North Carolina State University, 1998). Brown et al (1990) recommended varying buffer widths for wetlands in different landscapes of east central Florida. The distance to minimize groundwater drawdown varied from 20 to 550 feet, to control sedimentation, 75 to 375 feet, and to protect wildlife habitat, 322 to 732 feet (Brown et al, 1990). Brown et al (1990) recommended a wildlife buffer of 550 feet for forested wetlands and 322 feet for emergent wetlands. A literature search of studies on specific buffer performance 'found that for sediment removal, necessary widths ranged from 10 to 60 m; for nutrient and metals removal, widths ran from 4 to 85 m; for species distribution and diversity protection, from 3 to 110 m was required; and for water temperature moderation, requirements ranged from 15 to 28 m' (North Carolina State University, 1998). Castelle et al. recommended minimum buffer widths around 30 m under most circumstances to provide both basic physical and chemical buffering to maintain biological components of wetlands and streams (North Carolina State University, 1998). They noted that fixed-width buffer approaches are easier to enforce, but that variable-width buffers are more likely to provide adequate protection on a specific-case basis (North Carolina State University, 1998). A minimum 90 meter buffer around state and federal wildlife refuges and conservation areas has been recommended (North Carolina State University, 1998).
- # We sought buffer distances that would perform all of the functions listed above. We lacked data on groundwater depths. Based on Brown et al (1990), this was 550 ft for forested wetlands (distance to protect wildlife), and 325 ft for other wetlands (the midpoint between minimum and maximum distances to minimize groundwater drawdown).
- # Buffered unmodified wetlands (550' for FO, 325' for others).

- Define wetland complexes. Wetland complexes were defined as aggregations of wetlands plus their buffers, where the buffers were natural cover. Major roads were considered to be barriers.

- # Reclassified MRLC v3 to developed (classes 21,22,23,32,81,82,85 to value 0) and undeveloped (classes 11,31,33,41,42,43,91,92 to value 1).
- # Reclassified OP land use to urban (value 1) /non-urban (value 0).
- # Define major roads
  - * Query MD road coverage (SHA state roads) to extract interstate and state roads
  - * Convert to Boolean grid (1 = major roads, 0 = elsewhere).
- # Removed developed MRLC, urban OP LU, and major roads from wetland buffer.

- Wetland core areas were defined as wetland complexes with at least 250 ac of wetlands (equal to size threshold of interior forest).
  - # Compute wetland area in contiguous complexes
  - # Select wetland complexes with at least 250 ac of wetlands

" Aquatic core areas

- First, compared watershed land cover to MBSS data. For 1100-level watersheds, found no relationship between area of forest and wetlands, and IBI or imperiled aquatic species presence. The two data sets are at different spatial scales, so this isn't too surprising. But the MBSS data cannot be safely extrapolated to areas beyond their sample sites, stream reaches, and associated watersheds.
- Potomac River (provides aquatic link across entire western shore of Maryland)
  - # Selected upper Potomac (upstream of DC), and converted to Boolean grid
- Section of Youghiogheny river designated as 'wild' (unique resource in Maryland)
- Brook trout streams
  - #
  - # Scott Stranko (1999, personal comm.) wrote, "Streams that support brook trout are quickly becoming fewer and fewer. Brook trout are one of the most sensitive fish in Maryland to temperature impacts, siltation, etc. (and I have the data to prove it). Brook trout were once found all over the western half of Maryland - now they are pretty rare except where relatively large areas of forest and plenty of stream

shading occur. In fact, Brook trout only occur where the imperviousness in a watershed is less than 2% (that is a very small amount). The only way to keep streams cold and clean enough for brook trout is to keep the watersheds where they live forested."

Received point shapefile from Marty Hurd of brook trout sites. He added qualitative data in with normal (random) MBSS survey data to provide all of the locations.

Manually selected OP stream reaches corresponding to these sites. Also selected forested tributaries of these reaches, because trout (and the invertebrates which support them) are sensitive to siltation and pollution which might result from clearing these tributaries.

- Blackwater streams

Scott Stranko (1999, personal comm.) wrote: "In the Coastal Plain, there are several rare species of fish and other organisms that occur only in places with relativley large amounts of forested land. They include: the mud sunfish, banded sunfish, swamp darter, ironcolor shiner. These species only live in dark swampy waters that have not been channelized and drained for farming (and I have the data to prove it). These 'blackwater' streams are becoming more and more rare as swamps are drained for developments and farming. We can only protect them with forested watersheds and buffers. I have found them in Hardwood swamps too. Tanic acid leaches from leaves and stains many streams in hardwood as well as cypress forests. The key is slow flow so that the leaves have time to leach. I am very enthusiastic about protecting these rare coldwater and blackwater ecosystems. They are representative of the way streams in Maryland were before we started cutting down trees, channelizing streams, building roads, farming, etc. However, they are streams with relatively low richness (few species per meter) compared to many disturbed streams. That seems counter-intuitive but it is because the species that live there prefer unique habitats (cold water and dark, low pH water). As cold streams become degraded temperature rises making them more hospitable to species that prefer warmer streams and drives out the brook trout. The chemical composition of blackwater streams also changes with human impacts thus changing the species composition (a loss of biodiversity)."

Selected unmodified forested wetlands from NWI, water regimes C,E,F,G,H,J,Y,Z,L,M,N,P,R,T, and V (at least seasonally flooded, and not artificially flooded).

Selected where above swamps fell within large blocks of interior forest (at least 100 ac of contiguous interior forest, where interior forest was

defined as at least 300 feet from forest edge). Reclassify to values 1, No Data.

From OP stream file, removed drainage ditches `( [Order] = 49 )`

Clipped streams with polygon coverage of interior swamps.

Select only large stream groupings (large enough to sustain viable populations of mud sunfish, banded sunfish, swamp darter, and ironcolor shiner). Not sure how large this needs to be.

* ArcView: Convert shapefile '`op streams within interior swamp.shp`' to grid '`blackwater`' (value = 1 or NoData)

* Convert to length by dividing zonalarea by an average length of stream across the cell. Assume random orientation of streams within cells. Minimum distance across cell is 117.1257 ft, and maximum distance is 117.1257/cos(45 degrees) = 165.6408 ft. Split the difference (141.4 ft).

* Grid:
```
blackwater_ft = int( zonalarea(regiongroup(blackwater, #, eight)) / 141.1)
```

* Selected upper three quartiles

* Grid:
```
blackwat_core = con(blackwater_ft > 1700, 1)
```

* Convert to Boolean grid

- MBSS complementary watersheds

Selected complementary 8-digit watersheds for fish, amphibians, and reptiles from Southerland et al, 1998. Based on MBSS 1995-97 data.

Selected MBSS-delineated watersheds (upstream from sample sites) that contained aquatic spp. of concern in 1995-97 samples.

Selected those MBSS watersheds above that intersect complementary 8-digit watersheds.

Used these watersheds to select OP streams (excluding ditches). Convert to Boolean grid.

- MBSS stream reaches with Aquatic Species of Concern

MBSS data could be linked to MBSS stream reaches, but not MOP streams. Accordingly, assign MBSS stream reaches and aquatic indices to MOP streams (as far as possible).

* Stream reach file: `v:\streams\mdstream` (1:250,000 scale)

* Database file of aquatic indices by stream reach: `gr_in_mb.dbf` (dBASE format)
* The stream reach file was 1:250,000 scale, and does not overlay MOP streams exactly. To assign stream reach ID's and MBSS data to stream coverages and grids derived from MOP, used two steps.
    + Created grid with each cell assigned to the nearest stream reach (Spatial Analyst, Assign Proximity). Saved grid as `prox_mbss_str`.
    + Then, removed cells further than 700 ft from an MBSS stream reach, so that unsampled tributaries and ponds would not be assigned MBSS data. 700ft was chosen after examination of discrepancies between the two stream coverages. Buffered MBSS stream coverage a distance of 700 ft. Saved as `Mbss_mdstr_700ft_buffer.shp`. Converted to grid `Buff700ft_grd`
    + `Grid: prox_mbss_2 = con(buff700ft_grd, prox_mbss_str)`
* Link MBSS indices to stream reach.
    + Joined dbase table gr_in_mb.dbf to prox_mbss_2
    + Created 3 new fields, to give integer values for indices:
        • [ASCI] = [Ret_r] (range 0-10)
        • [fish_100] = [fish_110] * 10 (range 0-100)
        • [bent_100] = [bent_110] * 10 (range 0-100)

Aquatic Species of Concern Index

* The Aquatic Species of Concern Index (field ret_r) was developed using Wildlife and Heritage division listing information for amphibian, fish, crayfish and mussel species. Marty Hurd did not average this variable; if there were 3 sites on the reach, he scored it with the site that had the best combination of rare species. The index varied between 1-10:

Aquatic Species of Concern Index	**Found at site**
10	Two or more rare / endangered species present.
9	One or more rare / endangered species present.

8	Three or more threatened/candidate (for listing) species.
7	Two or more threatened/candidate (for listing) species.
6	One threatened/candidate (for listing) species.
1	Sampled, but none found.
0	Not sampled

* Create grid of ASCI scores for stream cells:
    + `([Riparian_grid] * [Prox_mbss_2 . Ret_r])`
    + Save grid as `mbss_asci_gr`
* Selected all stream reaches containing aquatic species of concern (mbss_asci_gr > 1), and converted to Boolean grid.

- Anadromous fish waters

    # Selected streams within 8-digit watersheds with an anadromous fish index of at least 8 (Maryland CWAP). The anadromous fish index is based on the number of ecologically valuable anadromous and semi-anadromous fish caught per haul. The scores range between 1 and 10, with 1 representing the most degraded sites, and 10 those with the best condition. It was assumed that fish passages could be built where human-created blockages occurred.

    # Anadromous and semi-anadromous fish were examined for all systems sampled under the Resource Assessment Service, Index of Biotic Integrity sampling program. An index was developed based on the mean catch per unit effort (CPUE) of anadromous and semi-anadromous species combined. Species included in the analysis were defined as follows: Anadromous Species included are American shad, Alewife, Blueback herring, Hickory shad, and Striped bass; Semi-anadromous species included are White perch and Yellow perch. The CPUE was calculated for every site on a yearly basis. The CPUE was then ranked into five groupings. The mean rank for each river was calculated. These ranks were then multiplied by two to adjust them to a scale ranging from 1 to 10. This index can serve as a fair measure of the value of juvenile anadromous/semi-anadromous fish habitat for each river system. This index was derived from fish information that is collected with gear that is biased toward juvenile fish communities. Data on adult populations would be a valuable addition to these analysis, as it would allow assessment of the river in terms of the entire fish population. For more information, see Clean Water Action Plan Technical Workgroup, 1998.

        - Converted to Boolean grid
    - Combine and buffer all these streams
        - Combine upper Potomac, Youghiogheny wild river section, brook trout streams, blackwater streams, MBSS complementary streams, stream reaches containing aquatic species of concern, and streams within watersheds with high anadromous fish scores. Saved as Boolean grid `core_aquatic`.
        - Buffer to floodplain (to maximum of 1000 feet) or 550 feet, whichever is greater.
- Add protected lands. Added:
    - Protected lands in MD (see protected.txt; pre-Chapman's purchase)
    - Chapman's Forest properties.
    - Delaware protected lands
    - Virginia Delmarva protected lands
    - Pennsylvania national wildlife preserves, national parks, national forests, state parks, state forests, and state game lands.
    - Data was unavailable for WV.
    - Combined, and saved grid as `all_protected`
- Combine layers from 2.2 - 2.6.
- Remove developed areas and major roads, and areas outside the study boundary.
- Remove all hub areas <100 ac
    - Some comparison metrics:
        - a circle consisting of all edge (for forest) would be <6.5 ac.
        - Almost all forest patches have more edge than a circle. The mean shape index for forest patches in Maryland was 1.34 (rather than 1 for square patches).
        - a circle with all habitat vulnerable to cowbirds would be <48.5 ac.
- Add adjacent wetlands and forest.
    - Spatial Analyst: Reclass land cover grid to wetland Boolean grid.

- Use grid `opmrlc_forest` to represent forest (areas classified as forest in both MRLC and 1997 OP LU).
- Combine forest and wetlands. Remove interstate, state, and county roads.
- Select wetlands and forest adjacent to hubs, to maximum of 1000 feet.
  - # Determine acres of woods/wetland groupings
  - # Omit groupings less than 100 ac (this will reduce computation time)
  - # Identify overlapping groupings at least 100 ac
  - # Identify areas within 1000 feet of hubs2
  - # Select groupings that overlap hubs
  - # Add these groupings to hubs

" Smooth edges (remove cells surrounded mostly by non-hub)

- `Grid: hubs3sum7 = focalsum(hubs3, rectangle, 7, 7, data) * hubs3`
- `Grid: hub3smooth7 = con(hubs3sum7 > 26, 1, 0) or con(isnull(hubs2), 0, 1)`
- `Grid: hubs4_fs7 = con(zonalarea(regiongroup(con(hub3smooth7 == 1, 1))) >= 4356000, 1) /* remove small separated sections`
- `Grid: hubs4sum7 = focalsum(hubs4_fs7, rectangle, 7, 7, data) * hubs4_fs7`
- `Grid: hub4smooth7 = con(hubs4sum7 > 26, 1, 0) or con(isnull(hubs2), 0, 1)`
- `Grid: hubs4b_fs7 = con(zonalarea(regiongroup(con(hub4smooth7 == 1, 1))) >= 4356000, 1) /* remove small separated sections`
- `Grid: hubs4sum3 = focalsum(con(isnull(hubs4b_fs7), 0, hubs4b_fs7), rectangle, 3, 3, data) * con(isnull(hubs4b_fs7), 0, hubs4b_fs7)`
- `Grid: hub4smooth3 = con(hubs4sum3 > 4, 1)`
- `Grid: hubs4smooth = con(zonalarea(regiongroup(hub4smooth3)) >= 4356000, 1) * ..\study_boundary\gi5_bnd_grd /* remove small separated sections`
- `Grid: hubs5 = con(hubs4smooth == 1, 1)`
- `Grid: hubs6 = ( con(eucdistance(hubs5 and hubs2) < 118, 1, 0) * wetl_or_woods ) or ( con(isnull(hubs5), 0, 1) ) /* re-add wetland or woods cells immediately adjacent to original hubs, if subtracted previously`

" Add undeveloped land cover (minus roads) in interior core gaps, if connected to hub.

- Identify gaps (holes) within hubs. Calculate the area of non-hub cell aggregations in acres, and discount area outside hubs (>10,000 ac)
- Set wetlands, woods, water, bare rock/sand, and transitional barren in gaps = 1; elsewhere = NoData
- Add to hubs
- Keep groupings at least 20 ac

" Give hubs separate ID's

- Eliminate groupings less than 100 ac.

! **Rank hubs by relative ecological importance within their physiographic provinces.**

" Link top hubs. Divide hubs into thirds. The top third is the top tier. Connect these hubs. The middle third is the second tier. Connect these to top tier hubs, corridors, and nodes. The lowest third is the third tier. Connect to the first two.

" Identify physiographic region of hubs

- Started with `\\gismd\coverags\physio\physiogr`. This coverage was poorly digitized, and did not register well.
- Converted to grid. Warped using 35 control points registered to the state boundary and the Chesapeake Bay. Used Grid function warp, with 4th order polynomial fit. Total RMS error was 431.426 ft in x direction, 360.72 ft in y direction.
- Saved grid as `e:\data\ecoregions\physiographic`
- Convert coverage `physiogr` to shapefile '`md physiographic regions.shp`', and add field [regionname], populated by the physiographic region name.
- Join attributes of coverage `physiogr` or shapefile '`md physiographic regions.shp`' by [`physiogr_`] to grid `physiographic` by [`Value`]
- Summarize physiographic regions (must create integer ID for each region) within zones of hubs_separate. Don't include water (assign as No Data). Assigned majority value to hub (saved as field [`maj_physio`]), as well as variety (saved as field [`num_physio`]). Joined physiographic name, then copied to new field.

- Hubs 12, 163, 171, 252, and 852 were entirely outside Maryland. Drop these for this study.

" Ecological ranking parameters

- Proximity to other hubs
  - # Importance = 6
  - # The proximity index is described in McGarigal and Marks, 1995, and is based on a gravity model (Forman and Godron, 1986; Forman, 1995). It equals the sum of patch area divided by the nearest edge-to-edge distance squared between the patch and the focal patch, of all patches of the corresponding patch type whose edges are within a specified distance of the focal patch (McGarigal and Marks, 1995). We used a search radius of 10 km.
  - # Methods
    - * Proximity index = (sum over all hubs within 10 km)
  - # NOTE: I was unable to calculate this metric. Fragstats could not handle such a large data set, and I could not get the data into a useable format for LEAP II or ARC*FRAGSTATS. As proxies, used area of proximity zone outside the hub, and nearest neighbor distance (described later).

- Proportion of gap area in hub
  - # Importance = 4
  - # The parameter value equals the total internal gap area divided by the total hub area.
  - # Calculations
    - * `Grid: not_hub_ac = int(zonalarea(regiongroup(con(isnull(hubs_separate), 1), #, four)) / 43560)`
    - * `Grid: hub_gaps = con(not_hub_ac < 10000, 1)`
    - * Spatial Analyst: Assign Proximity to Hubs_separate
    - * Tabulate area of hub gaps within zones of Proximity to Hubs_separate.
    - * Convert ft^2 to ac.

* Export as 'hub acres of internal gaps.dbf', with field [int_gap_ac] = acres of internal gaps within the hub
* Join to hub table.
* Divide by total hub area.

Reasoning: Prefer intact hubs, with minimal restoration needs.

- Area of upland Natural Heritage Areas (NHA)

Importance = 5

The parameter value equals the area of upland NHA within the hub.

Calculations in ArcView:

* Reclassify Md_10mi_lc to 1 = upland (classes 21-85), 2 = wetland or open water (classes 11, 91-92)
* Multiply ([Reclass of Md_10mi_lc] * [Nha])
* Tabulate areas of map calculation by hub.
* Convert ft^2 to ac. Export table as 'hub NHA acres.dbf'
* Join to hub table.
* Total NHA acres can be derived by adding fields [upl_nha_ac] and [wet_nha_ac].

Reasoning: Criteria for qualifying as an NHA are: '(1) Contain one or more threatened or endangered species or wildlife species in need of conservation; (2) Be a unique blend of geological, hydrological, climatalogical or biological features; and (3) Be considered to be among the best Statewide examples of its kind.'

Note: Designation of NHA was developed in conjunction with the Critical Area Law and most fall within the Chesapeake Bay Critical Area. Sites outside the Critical Area are already owned by a public agency.

- Area of Wetlands of Special State Concern (WSSC), or wetland and open water Natural Heritage Areas (NHA)

Importance = 5

The parameter value equals the area of WSSC and wetland or open water NHA within the hub.

Calculations in ArcView:

* Tabulate area of WSSC by hub.

* Convert ft^2 to ac.
* Export table as 'hub WSSC acres.dbf'
* Add acres of WSSC and acres of wetland or open water NHA (field [wet_nha_ac] in 'hub NHA acres.dbf').
* Export table as 'hub WSSC and wetland or water NHA.dbf'. Field is [wsscwnhaac].

Reasoning: Criteria for qualifying as an NHA are: '(1) Contain one or more threatened or endangered species or wildlife species in need of conservation; (2) Be a unique blend of geological, hydrological, climatalogical or biological features; and (3) Be considered to be among the best Statewide examples of its kind.' WSSC are wetlands containing rare, threatened, or endangered species, or unique habitat.

Note: Designation of NHA was developed in conjunction with the Critical Area Law and most fall within the Chesapeake Bay Critical Area. Sites outside the Critical Area are already owned by a public agency.

- Area of upland interior forest

#

Importance = 3

The parameter value equals the area of upland interior forest within the hub.

Calculations in Spatial Analyst:

* Reclass grid dist_wdedge to >=300 = interior forest, No Data = elsewhere.
* Reclass grid Md_10mi_lc to values 1 = upland forest (class 41-43), No Data = elsewhere.
* Multiply ([Reclass of Md_10mi_lc] * [Reclass of Dist_wdedge]) to get upland interior forest.
* Save grid as 'upland_intfor'
* Tabulate upland interior forest area by hub (hubs_separate).
* Convert ft^2 to ac.
* Export table as 'hub acres of upland interior forest.dbf'
* Join to hub table.

Reasoning: habitat for upland interior forest species

- Area of wetland interior forest
    - # Importance = 3
    - # The parameter value equals the area of wetland interior forest within the hub.
    - # Calculations in Spatial Analyst:
        - * Reclass grid dist_wdedge to >=300 = interior forest, No Data = elsewhere.
        - * Reclass grid Md_10mi_lc to values 1 = woody wetland (class 91), No Data = elsewhere.
        - * Multiply ([Reclass of Md_10mi_lc] * [Reclass of Dist_wdedge]) to get wetland interior forest.
        - * Save grid as 'wetl_intfor'
        - * Tabulate wetland interior forest area by hub (hubs_separate).
        - * Convert ft^2 to ac.
        - * Export table as 'hub acres of wetland interior forest.dbf'
        - * Join to hub table.
    - # Reasoning: habitat for wetland interior forest species

- Area of other unmodified wetlands
    - # Importance = 2
    - # The parameter value equals the area of unmodified wetlands, other than those in NHA, WSSC, or interior forest, within the hub.
    - # Calculations in Spatial Analyst:
        - * Reclassify grids `Wetl_intfor, Upland_intfor, Wssc`, and `Nha` to Boolean grids.
        - * Calculate `[Wetland_unmod] - ( ([Reclass of Nha]) or ([Reclass of Wssc]) or ([Reclass of Upland_intfor]) or ([Reclass of Wetl_intfor]) ).`
        - * Reclassify to Boolean grid. Save as '`wetl_other`'.
        - * Tabulate area of wetl_other by hub (`hubs_separate`).
        - * Convert [`Value-1`] ft^2 to ac.
        - * Export table as '`hub acres of other unmodified wetlands.dbf`', with fields [`value`] = hub ID; [`otherwetac`] = acres of other wetlands in hub.
        - * Join to hub table.

- # Reasoning: Eliminate spatial overlap with parameters calculated previously. Unmodified wetlands not included in NHA, WSSC, or interior forest are still important.

- Length of streams within interior forest
  - # Importance = 3
  - # The parameter value equals the length of OP streams within interior forest (at least 300ft from edge) within the core area.
  - # Calculations: Used ARC Identity function and summed length in feet by core area
    - * `Arc: gridpoly hubs_separate hubs_poly`
    - * `Arc: clean hubs_poly # 0 .001 poly`
    - * `Grid: int_forest = con(e:\data\Interior_forest_2\dist_wdedge >= 300, 1)`
    - * `Arc: gridpoly int_forest intfor_poly`
    - * `Arc: clean intfor_poly # 0 .001 poly`
    - * `Arc: clip e:\data\streams\mop_streams intfor_poly intfor_strms line`
    - * `Arc: identity intfor_strms hubs_poly ifstrm_by_hub line .001 join`
    - * ArcView: Convert to shapefile '`interior forest streams by hub.shp`'.
    - * ArcView: Remove `[order] > 6 and [grid-code] < 1`
    - * ArcView: in table, sum [`length`] by [`grid-code`].
    - * Export as '`hub length of interior forest streams.dbf`'. Field [`ifstrm_ft`] is feet of interior forest streams.
    - * Join to hub table.
  - # Reasoning: Streams within interior forest are more likely to contain pristine aquatic and riparian conditions than unforested streams. These areas provide important aquatic habitat, are a source of water, and improve water quality.

- Number of stream nodes (sources and junctions)
  - # Importance = 2

The parameter value equals the number of stream sources and stream junctions within the core area.

Calculations: Create point coverage of stream nodes, use Identity function to identify core area, and sum by core area

* `Arc: w d:\data\streams`
* `Arc: build stream_cov line`
* `Arc: renode stream_cov`
* `Arc: nodepoint stream_cov stream_nodes`
* `Arc: build stream_nodes point`
* `Arc: pointgrid stream_nodes str_node_grid /* convert to grid`
* Spatial Analyst: Reclass to values 1, No Data
* Spatial Analyst: Summarize within zones of hubs_separate. [Count] is the number of stream nodes.
* Spatial Analyst: Export as '`hub number of stream nodes.dbf`'

Reasoning: The most probable location of a large node of native riparian vegetation is at a stream intersection (Forman 1995). Stream sources, which include intermittent streams, springs, or seepages, are unusual microhabitats in the basin (Forman 1995). They normally exhibit a high water table, slow water movement, and shady conditions, favoring some rare species (Forman 1995). Further, stream sources require vegetation buffering to maintain water quality.

- Mean fish IBI score

Importance = 1

The parameter value equals the mean fish IBI score within the hub, if the stream width was greater than 1.5 meters. If there were no FIBI sample sites within the hub, the mean FIBI score for the 8-digit watershed was used. If there were no FIBI scores for that watershed, the hub was assigned a neutral score (the IBI midpoint, or 2.5). Most of these latter were tidal watersheds, which were not sufficiently sampled for non-tidal fish.

Calculations in ArcView:

* Convert grid `Hubs_separate` to shapefile `Hubs_separate.shp`.

* Identity on St94567.shp (shapefile of 1994-7 sample sites) and Hubs_separate.shp.
* Select ([Avgwid] > 1.5) and ([Fibi_98] > 0)
* Summarize average and count of [Fibi_98] by [gridcode]
* In summary, select ([gridcode] > 0)
* Export as 'hub FIBI mean and sample count.dbf'. Field [mean_FIBI] is the mean FIBI, and [num_sites] is the number of sample sites.
* Join to hub table.
* Join table aquatic.dbf to inrashed.shp.
* Identity on Hubs_separate.shp and Inrashed.shp.
* Select ([Fishibi] > 0)
* Summarize average of [Fishibi] by [gridcode]. Divide by two to make compatible with site IBI scores ([wshed_FIBI] = [Ave_fishib] / 2).
* Export as 'hub mean INRA watershed FIBI.dbf'. Field [wshed_FIBI] is the mean of watershed FIBI scores within the hub.
* For hubs not falling within a watershed with a FIBI score, assign a neutral score of 2.5.

Reasoning: Streams with high biotic integrity. Not all streams were sampled, so parameter was given low weighting.

- Mean benthic invertebrate IBI score

Importance = 1

The parameter value equals the mean benthic invertebrate IBI score within the hub. If there were no BIBI sample sites within the hub, the mean BIBI score for the 8-digit watershed was used. If there were no BIBI scores for that watershed, the hub was assigned a neutral score (the IBI midpoint, or 2.5). Most of these latter were tidal watersheds, which were not sufficiently sampled for non-tidal invertebrates.

Calculations in ArcView:

* Convert grid Hubs_separate to shapefile Hubs_separate.shp (done previously).
* Identity on St94567.shp (shapefile of 1994-7 sample sites) and Hubs_separate.shp (done previously).

* Select ([Bugibi] > 0)
* Summarize average and count of [Bugibi] by [gridcode]
* In summary, select ([gridcode] > 0)
* Export as 'hub BIBI mean and sample count.dbf'. Field [mean_BIBI] is the mean BIBI, and [num_sites] is the number of sample sites.
* Join to hub table.
* Join table aquatic.dbf to inrashed.shp (done previously).
* Identity on Hubs_separate.shp and Inrashed.shp (done previously).
* Select ([Benibi] > 0)
* Summarize average of [Benibi] by [gridcode]. Divide by two to make compatible with site IBI scores ([wshed_FIBI] = [Ave_benibi] / 2).
* Export as 'hub mean INRA watershed BIBI.dbf'. Field [wshed_BIBI] is the mean of watershed BIBI scores within the hub.
* For hubs not falling within a watershed with a BIBI score, assign a neutral score of 2.5.

Reasoning: Streams with high biotic integrity. Not all streams were sampled, so parameter was given low weighting.

- Richness of sampled aquatic species of concern

Importance = 2

The parameter value equals the number of aquatic species of concern, multiplied by 2 for RTE spp., and by 1 for possibly rare spp., sampled within the hub. Hubs with MBSS sample sites, but no recorded aquatic species of concern, were given a score of -1. Hubs with no MBSS sample sites were given a null score of 0.

Calculations in ArcView:

* From RET_f_s.dbf, give each species a unique ID. Save as "aquatic rte species.dbf".
* Copy st94567.shp to "MBSS sites with hub ID.shp", and add x,y coordinates with script View.AddXYCoordToFTab.

* Perform identity operation on shapefile using Hubs_separate.shp.
* Join to "aquatic rte species.dbf" by field [siteyr].
* Delete records without site ID's.
* Convert to shapefile (Add Event Theme).
* Save as "aquatic rte spp by hub.shp".
* Had to manually count number of species for each hub. Multiply RTE spp. occurrences ([ret] > 1) by 2. Enter in field [aq_rarespp].
* Summarize maximum [aq_rarespp] by [grid_code].
* Join summary table to "MBSS sites with hub ID.shp" by [grid_code].
* Create field [aq_rarespp], and calculate [aq_rarespp] = [Max_aq_rar].
* Delete records with [grid_code] = 0.
* Select records with no aquatic species of concern ([aq_rarespp] = Null), and calculate field [aq_rarespp] = -1.
* Summarize maximum [aq_rarespp] by [grid_code].
* Join to hub table.
* Export as "hub aquatic rte spp.dbf".
* Create field [aq_rarespp], and calculate [aq_rarespp] = [Max_aq_rar].
* Select records with no MBSS sample sites ([aq_rarespp] = Null), and calculate field [aq_rarespp] = 0.
* Delete fields other than [Value] and [aq_rarespp].
* Join to hub table.

Reasoning: Streams with rare species. Not all streams were sampled, so parameter was given low weighting.

- Presence of brook trout

Importance = 1

The parameter value equals 1 if brook trout were sampled within the hub, and 0 if not.

Calculations in Spatial Analyst:

* Buffer `Dr_brktrt.shp` 500 feet to compensate for horizontal positional inaccuracy (1:250,000).
* Add field [`presence`] to buffer. Calculate [`presence`] = 1 for all records.
* Convert buffer to grid dr_brktrt, using field [`presence`].
* Summarize `dr_brktrt` by zones of `hubs_separate`. Field [`Max`] = 1 shows presence of brook trout.
* Exported as '`hub presence of brook trout.dbf`'. Field [`brooktrout`] = 1 indicates presence of brook trout.
* Join to hub table.

Reasoning: brook trout are highly sensitive to watershed disturbance, and a good indicator species in cool-water streams. Not all streams were sampled, so parameter was given low weighting.

- Anadromous fish index

Importance = 1

The parameter value equals the anadromous fish index score for the 8-digit watershed the hub falls within. If the hub falls within more than one watershed, use the highest AFI score. The AFI score varies between 1 and 10, with 1 in the worst condition, and 10 in the best condition (see CWAP report). If there were no AFI scores for that watershed, the hub was assigned a neutral score (the AFI midpoint, or 5). Most of these latter were nontidal watersheds.

Calculations in Spatial Analyst:

* Join table `tidal.dbf` to `inrashed.shp`.
* Convert `inrashed.anadromous` to grid `afi`, with same map extent and cell size as `hubs_separate`.
* Summarize grid `afi` within zones of `hubs_separate`.
* Export as '`hub highest INRA watershed AFI.dbf`'. Field [`max_AFI`] is the maximum watershed AFI score within the hub.
* For hubs not falling within a watershed with a AFI score, assign a neutral score of 5.
* Join to hub table.

Reasoning: Anadromous fish require streams and rivers for spawning. Data sampling was coarse, so parameter was given low weighting.

- Area of Sensitive Species Project Review Areas (SSPRA), not including WSSC and NHA.
    - # Importance = 2
    - # The parameter value equals the area of SSPRA, excluding WSSC and NHA, within the hub.
    - # Calculations in Spatial Analyst:
        - * Convert WSSC and NHA to Boolean grids.
        - * Map Query `( [Sspra_grid2] ) and ( not ( [Reclass of Nha] or [Reclass of Wssc] ) )`
        - * Tabulate area by hub.
        - * Convert [`Value-1`] ft^2 to ac.
        - * Export table as '`hub acres of other SSPRA.dbf`', with fields [`value`] = hub ID; [`othersspra`] = acres of SSPRA, excluding WSSC and NHA, within the hub.
        - * Join to hub table.
    - # Reasoning: Eliminate spatial overlap with WSSC and NHA, which subsets of SSPRA. Remaining SSPRA contain rare, threatened, and endangered species, Habitat Protection Areas, Colonial Waterbird Sites, and Waterfowl Concentration and Staging Areas. SSPRA polygons fall only within Maryland, and are larger than the crucial habitat they contain.

- For eastern shore only, percent upland forest that is deciduous or mixed
    - # Importance = 4
    - # The parameter value equals the percent of upland forest within the hub that is deciduous or mixed.
    - # Calculations in Spatial Analyst:
        - * Select hubs (`hubs_separate`) in Eastern Shore (`[Regionname] = 'Coastal Plain, east'`).
        - * Reclass grid `Md_lc9901_s27` to value 1 = deciduous or mixed forest, 0 = evergreen forest, No Data = elsewhere.
        - * Summarize reclassed grid within zones of `hubs_separate`.
        - * Calculate field `[pct_decmix] = [Mean] * 100`.

- Export table as "eastern shore pct deciduous or mixed forest.dbf".
- Join to hub table.
- A few hubs had no forest (all salt marsh). Don't penalize; give score of 90.

Reasoning: On eastern shore, especially lower eastern shore, pine forests are probably managed loblolly, which has much lower ecological value than a natural forest.

- Topographic relief (standard deviation of elevation)

Importance = 1

The parameter value equals the standard deviation of elevation values for all cells in the hub.

Calculations:

- See '*DEM methods.txt*' for creating grid DEM_m_27ft.
- Spatial Analyst: Summarize DEM_m_27ft within zones of hubs_separate.
- Export table as "hub elevation data.dbf".
- Join to hub table.

Reasoning: Higher diversity of communities where there is topographic relief (vertical stratification). Parameter was given low weighting because standard deviation of elevation was only an approximate measure of this effect.

- Number of wetland types

Importance = 1

The parameter value equals the number of different NWI wetland types within the hub, using all codes except modifiers and haline/saline.

Calculations in Spatial Analyst:

- Convert nwi_md.integer_co to grid nwi_type
- Summarize nwi_type by zones of hubs_separate. Field [Variety] is the number of unique wetland types. Also retained field [Count] (the number of wetland polygons within the hub).

* Exported as 'hub number of wetland types.dbf'. Field [wetl_types] is the number of unique wetland types within the hub. Field [wetl_num] is the number of wetland polygons within the hub.
* Join to hub table.

Reasoning: Contributing variable toward potential wetland complexity and diversity.

- Number of soil types

Importance = 1
The parameter value equals the number of different natural soil groups within the hub.
Calculations in Spatial Analyst:

* Select MD soil groups (md_soils.shp) other than 50, HL, Ma, Unc, and Wa ([Soil_code] < 890).
* Convert md_soils.soil_code to grid soil_type
* Summarize soil_type by zones of hubs_separate. Field [Variety] is the number of unique soil types.
* Exported as 'hub number of soil types.dbf'. Field [soil_types] is the number of unique soil types within the hub.
* Join to hub table.

Reasoning: Contributing variable toward potential diversity of plant communities.

- Number of physiographic regions in hub

Importance = 1
The parameter value equals the number of different physiographic regions within the hub.
Calculated in 3.3.
Reasoning: Indirect measure of possible floristic and ecosystem diversity.

- Remoteness from major roads

Importance = 3

The parameter value equals the zonalmean distance to the nearest primary or secondary road for all cells in the hub.

Methods

* `Grid: prisecrds = con( %.rd%\primary_rds or %.rd%\secondary_rds, 1 )`
* `Grid: dist_roads = int(eucdistance(prisecrds))`
* `Grid: hubarea_rdist = int(zonalmean(hubs_separate, dist_roads, DATA))` /* mean distance to nearest road in feet for that hub
* Spatial Analyst: Summarize `hubarea_rdist` by hub.
* Exported as "`hub mean feet to nearest major road.dbf`". Field [`majrd_dist`] is the mean distance to the nearest primary or secondary road for all cells in the hub, in feet.
* Join to hub table.

Reasoning: Roads are a source of disturbance. Many studies have correlated increasing road density with wildlife avoidance (Forman 1995). See Appendix for more details.

- Road density in hub (interstate, state, and county roads)

Importance = 3

The parameter value equals the length of interstate, state, and county roads within the hub, divided by hub area. All roads in SHA road file are considered (`state_roads`).

Methods

* Convert shapefiles of interstate, state, and county roads to line coverages.
* In Arc, append these together
* `Arc: append roads line all`
* `Arc: matchnode roads` /* takes hours; omit if roads won't be used later
* `Arc: build roads line`
* `Arc: identity roads hubs_poly roads_by_hub line .001 join`
* ArcView: select records of `roads_by_hub` with [`gridcode`] > 0. Convert to shapefile '`roads by hub.shp`'.

* ArcView: in table, sum [length] by [`gridcode`]. Save as '`hub feet of interstate state and county roads.dbf`'.
* ArcView: Join to hub table.

Reasoning: Roads are a source of disturbance. Many studies have correlated increasing road density with wildlife avoidance (Forman 1995). See Appendix for more details.

- Area of highly erodible soils

Soil loss to erosion can be predicted using the universal soil loss equation (Brandy, 1990): A = RKLSCP; where A = the predicted soil loss, R = climatic erosivity (rainfall and runoff), K = soil erodibility, L = slope length, S = slope gradient or steepness, C = cover and management, and P = erosion control practice

Assuming rainfall is fairly constant within physiographic provinces, and that C and P can be controlled by management, we focused on K, L, and S. We used the Natural Soils Groups of Maryland, which is described in Maryland Department of State Planning (1973). Mary Searing created a table with K values for these soils. Soils occurring on steep slopes were identified from Maryland Department of State Planning, 1973. B1c, B2b, B2c, B3, C2, and E2b soils were targeted for remaining in natural vegetation, preferably wooded, because of their high erodibility.

* A1 soils are sandy, and extremely susceptible to erosion by wind when dry and without vegetative cover. They are possible groundwater recharge areas.
* A2 soils are beach sands.
* B1 soils are well drained and permeable.
* B2 soils are well drained, but slowly permeable below 2-3 ft.
* B3 soils are clays with poor stability.
* C1 soils are rocky, shallow soils.
* C2 soils are well-drained and clayey.
* D1 soils are rocky, shallow soils.
* E1 soils are moderately well drained and sandy.
* E2 soils are saturated by a perched water table part of the year.
* E3 soils are deep, moderately well drained, silty soils.

* F1 soils are the wettest sandy soils in the state, with a water table at or near the surface much of the year.
* F2 and F3 soils are poorly or very poorly drained.
* G1 and G2 soils are deep, well drained or moderately well drained riparian floodplain soils. G3 soils are in marshes or swamps. They are saturated, and have standing water most or all of the year.

Importance = 2

The parameter value equals the total area B1c, B2b, B2c, B3, C2, and E2b soil polygons within the hub.

Calculations in Spatial Analyst:

* Selected highly erodible soils from the Natural Soils Groups of Maryland coverage: `([Soil_type] = "B1c") or ([Soil_type] = "B2b") or ([Soil_type] = "B2c") or ([Soil_type] = "B3") or ([Soil_type] = "C2") or ([Soil_type] = "E2b")`
* Converted to Boolean grid (`e:\data\soils\hi_erode_soil`).
* Tabulate acres of highly erodible soils by hub.
* Export table as '`hub acres of highly erodible soils.dbf`'.
* Join to hub table.

Reasoning: Protect against soil erosion by maintaining plant cover (especially if trees). The spatial resolution is 1:63,360.

- Area of proximity zone outside hub

Importance = 2

This represents the degree of isolation from other hubs.

Calculations:

* Spatial Analyst: Calculate proximity zones to grid `hubs_separate`. Save grid as `hub_proximity`.
* `Grid: hub_prox2 = hub_proximity * con(e:\data\Green_Infrastructure_v5\study_boundary\gi5_bnd_grd == 1, 1)` /* Remove area outside study boundary
* Convert number of `hub_prox2` cells to acres (multiply `[Count] * 0.3149318`), and export as '`hub proximity`

area.dbf". Subtract area of hub to get area of proximity zone outside hub (Calculate [surrproxac] = [totprox_ac] - [Total_ac])

Reasoning: Crude measure of proximity to other hubs. Could not calculate proximity index metric from FRAGSTATS for such a large data set. Hubs with large proximity zones did not have other hubs nearby; those with small proximity zones were surrounded by neighboring hubs.

- Nearest neighboring hub distance
  # Importance = 3
  # This is a rough measure of connection feasibility to other hubs.
  # Calculations:
    * Spatial Analyst: Calculate proximity zones to grid hubs_separate (done previously).
    * ArcView: Convert to shapefile.
    * ArcView X-Tools: Convert polygon shapefile to polyline shapefile (proximity boundaries).
    * Convert to Arc line coverage (ArcView buffering takes too long).
    * Arc: buffer proxlines proxbndbuf # # 117 .001 line round full /* Buffer proximity boundaries 117 feet (1 grid cell).
    * Arc: polygrid proxbndbuf proxbnd_grid inside
    * Grid: hub_prox_bnds = con(proxbnd_grid == 100, 1)
    * Grid: dist_hubs = int(eucdistance(con(hubs_boolean == 1, 1)))
    * Grid: proxbnd_dist1 = hub_prox_bnds * dist_hubs
    * Grid: proxbnd_dist2 = con(proxbnd_dist1 > 0, proxbnd_dist1) * con(e:\data\Green_Infrastructure_v5\study_boundary\gi5_bnd_grd == 1, 1) /* remove distances of 0 and distances outside study boundary
    * Grid: hub_min_dist = zonalmin(hub_proximity, proxbnd_dist2, DATA) * 2 - 117 /* multiply distance by

2, and subtract distance of one cell width, since proximity boundaries are halfway between hubs.

* Spatial Analyst: Summarize `hub_min_dist` within zones of `Hubs_separate`.
* Export as dBASE file "`hub nearest neighbor distance.dbf`". Field [`nearesthub`] is the distance to the nearest neighboring hub in feet.

- Patch shape
  - # Importance = 1
  - # We used the shape index from FRAGSTATS (McGarigal and Marks, 1995). The shape index equals patch perimeter divided by the square root of patch area, adjusted by a constant. The shape index = 1 when the patch is circular (vector) or square (raster), and increases without limit as patch shape becomes more irregular.
  - # Calculate shapeindex = (0.25 * zonalperimeter) / sqrt(zonalarea)
    * `Grid: shapeindex = (0.25 * zonalperimeter(hubs_separate)) / sqrt(zonalarea(hubs_separate))`
    * Spatial Analyst: Summarize `shapeindex` by hub.
    * Save as '`hub shape index.dbf`'.
    * Join to hub table.
  - # Reasoning: The shape index indicates the proportion of edge to interior of the hub.
  - # Limitations: Perimeter is dependent on scale.
  - # In future, weight by area - the larger the hubs, the less important shape is.

- Surrounding buffer suitability (within 300' of hub).
  - # Importance = 1
  - # Reclass MRLC, version 3 (grid `Md_10mi_lc`) to reflect suitability of land cover as buffer. Saved grid as `mrlc_compat`.

MRLC (version 3)	**Code**	**Buffer suitability score**
Open water	11	33

Low intensity developed	21	5
High intensity residential	22	1
High intensity commercial/industrial	23	0
Bare rock/sand	31	33
Quarries/strip mines/gravel pits	32	10
Transitional barren	33	33
Deciduous forest	41	100
Evergreen forest	42	90
Mixed forest	43	100
Hay/pasture	81	33
Row crops	82	20
Urban grass	85	20
Woody wetlands	91	100
Emergent wetlands	92	50
NoData	0, NoData	NoData

Give road cells a suitability score of 0 for primary roads, 1 for secondary roads, 5 for county roads

*
```
Grid: buffer_suit = merge(
con(d:\data\roads_2\primary_rds == 1, 0),
con(d:\data\roads_2\secondary_rds == 1, 1),
con(d:\data\roads_2\county_rds == 1, 5),
mrlc_compat )
```

The parameter value equals the zonalmean value for all cells within 300' of the core.

* Ran program `hub_surrounding_land_cover.aml` (see Appendix). Separated MD into 3 regions to speed calculations, then recombined text file outputs in Quattro.

* Exported as "`hub 300ft buffer suitability.dbf`".

Reasoning: The intensity of land use affects ecological processes in the core area. Forest surrounding the core serves as a buffer, and will increase wildlife habitat, whereas development surrounding the core will

be a source of disturbance (noise, pollution, domestic animal intrusion, etc.)

- Interior forest within 10 km of hub periphery
  - # Importance = 1
  - # The parameter value equals the acres of interior forest within 10 km of the hub periphery.
  - # Calculations:
    - * Arc: Convert grid hubs_separate to polygon coverage.
    - * ArcView: Select `[Grid-code] > 0`, and convert to shapefile `hubs_separate.shp`.
    - * ArcView: Buffer `hubs_separate.shp` using Create Buffer and script `buf_w_at.ave`. Retain attribute [`Grid-code`]. Runs out of memory unless doing about 100 at a time, and simplifying hub #654 (Blackwater/Fishing Bay). Was unable to get buffer program to only create external buffers.
    - * ArcView: After creating 10 km buffers, merge shape by [`Grid-code`].
    - * ArcView: Merge these themes. Save as "`hub 10km buffers.shp`".
    - * Spatial Analyst: Reclassify grid `intfor300ftac` to 1, NoData. Save as `e:\data\temp\int_forest`.
    - * Spatial Analyst: Tabulate area of `e:\data\temp\int_forest` within [`Grid-code`] zones of "`hub 10km buffers.shp`".
    - * Spatial Analyst: Tabulate area of `e:\data\temp\int_forest` within zones of `hubs_separate`.
    - * Spatial Analyst: Convert ft^2 to ac.
    - * Spatial Analyst: Subtract area of interior forest within zones of `hubs_separate` from area of interior forest within zones of "`hub 10km buffers.shp`", to get area of interior forest just within 10 km of periphery of hubs (field = [`ifacin10km`]). Where no data (no interior forest) within hubs, copy values of area of interior forest within zones of "`hub 10km buffers.shp`". Export as "`hub ac of interior forest within 10km of periphery.dbf`".

- Join to hub table.

Reasoning: Jim McCann (1999) wrote, "Consider adding the parameter 'surrounding landscape cover'... The importance weighting for this parameter should be high. There is ample evidence for forest birds (and to varying degrees, for other taxa; e.g., certain far-ranging mammals) that the ability of a forest tract or 'hub' to support viable populations of area-sensitive species is related not only to parameters that describe an individual forest tract (e.g., forest tract size, edge:area ratio, degree of isolation, etc.) but the percent of forest in the surrounding landscape. Although much less published information is available, similar relationships appear to exist for other land cover types (e.g., tidal marsh, upland grasslands). For forests, this parameter has been defined by some as the percent of forest cover within 10 km of the centroid of a forest or the percent of forest within 10 km of the periphery of the forest tract. I would suggest that, at least for forests, 'surrounding landscape cover' be defined as the percentage of forest interior habitat with 10 km of the hub periphery. Possible cover categories are: low = < 30%; medium = 30-60%; high = > 60%... but I'm not sure how a 'suitability' value might be derived. Similar categories have been used by researchers investigating bird-habitat relationships and their findings indicate that these categories have biological relevance (for forest birds). These categories also have been incorporated into a draft DNR guidance paper on timber harvesting guidelines for FIDS in the Critical Area."

Robinson et al (1995) found that percent forest cover within 10 km of study sites was negatively correlated with cowbird parasitism and predation of neotropical migrant bird nests in the midwest U.S.

- Marsh within 10 km of hub periphery

Importance = 1

The parameter value equals the acres of marsh within 10 km of the hub periphery.

Calculations in ArcView:

- 10 km buffers ("`hub 10km buffers.shp`") were created previously.
- Reclassify grid `md_10mi_lc` to 1 = marsh, 0 = elsewhere. Save as `e:\data\temp\marsh`.
- Tabulate area of `e:\data\temp\marsh` within [`Grid-code`] zones of "`hub 10km buffers.shp`".

- * Tabulate area of `e:\data\temp\marsh` within zones of `hubs_separate`.
- * Convert ft^2 to ac.
- * Subtract area of marsh within zones of `hubs_separate` from area of marsh within zones of "`hub 10km buffers.shp`", to get area of marsh just within 10 km of periphery of hubs (field = [`maacin10km`]). Where no data within hubs, copy values of area of marsh within zones of "`hub 10km buffers.shp`". Export as "`hub ac of marsh within 10km of periphery.dbf`".

Join to hub table.

Reasoning: Similar to forest within 10 km of hub

" Combination of ecological parameters

- In spreadsheet, rank hubs from highest to lowest for each parameter above, except for gap proportion and a few others, which rank from lowest to highest.
- Multiply ranking by the parameter's importance weighting. Parameters were chosen and weighted according to feedback from biologists and natural resource managers; literature reviews; minimization of redundancy, area dependence, and spatial overlap; balancing different ecotypes; data reliability; and examination of output from different combinations.

Parameter	**Weight**
Proportion of internal gaps	4
Area of upland Natural Heritage Areas	5
Area of WSSC and wetland or aquatic NHA	5
Area of upland interior forest	4
Area of wetland interior forest	4
Area of other wetlands	3
Length of streams within interior forest	4
Number of stream nodes (sources and junctions)	2
Fish IBI score	1
Benthic invertebrate IBI score	1

Aquatic species of concern	2
Presence of brook trout	1
Anadromous fish index	1
Area of SSPRA, not including WSSC and NHA	2
Presence of SSPRA or aquatic species of concern	2
Percent upland forest that is deciduous or mixed	4
Standard deviation of elevation	1
Number of different NWI wetland types	1
Number of different natural soil groups	1
Number of different physiographic regions	1
Mean distance to the nearest primary or secondary road	3
Density of interstate, state, and county roads	3
Area of highly erodible soils	2
Area of proximity zone outside hub	2
Nearest neighboring hub distance	3
Shape index	1
Surrounding buffer suitability (within 300' of hub)	1
Interior forest within 10 km of hub periphery	1
Marsh within 10 km of hub periphery	1

- Add rankings multiplied by their importance weighting.
- Use above linear combination to rank hubs from highest to lowest.
- Sum number of hubs by physiographic region. Save as "`number of hubs per physio region.dbf`". After joining "`hub physiographic region.dbf`" to `hub_separate`, join "`number of hubs per physio region.dbf`" by [maj_physio]. Use field [`num_hubs`] (number of hubs per physiographic region) to normalize [`eco_rank`].
- Reasoning: Used nonparametric ranking because we lacked information needed to evaluate thresholds (e.g., what density of stream nodes is desirable?) or to standardize parameters (they were in different units). All core areas are

considered ecologically important, and all should receive protection, but the above parameters can be used for relative rankings.

" Create grid with hubs separated into three tiers by equal-number distribution within each physiographic region. Value 1 = the top-ranked third of hubs; 2 = the middle third; 3 = the bottom third. Hubs falling entirely outside MD were not ranked.

- Spatial Analyst: Map Calculator `( ( ( [Hubs_separate . Eco_rank] * 3 ) / [Hubs_separate . Num_hubs] ) + 1 ) .Int`
- Spatial Analyst: Reclassify value 4 to value 3. Save grid as hub_tiers.

! **Link top tier of hubs with corridors**

" Least cost paths (LCP) for upland wildlife

- Maryland historically was dominated by forest (Besley, 1916; Powell and Kingsley, 1980). Link core areas of interior upland forest. The best corridors between core areas are streams with wide riparian buffers and healthy aquatic communities (Harris, 1984; Forman and Godron, 1986; Brown et al., 1990). Other landscape features, such as forested ridge lines and valleys, may also provide adequate corridors.

- Core areas

Reclass MRLC v3 to upland forest (41-43 to 1) or elsewhere (to 0)
Select upland forest at least 300' from non-forest (forested wetlands count as forest)
Select upland interior forest within top-ranked third of hubs.
Select those groupings at least 100 ac, and save as upland_cores

- Impedance

Land cover impedance (starting grid)

* Source is MRLC, version 3 (grid `md_10mi_lc`).

* Convert land cover to impedances. Estimated passability and food and cover availability (wildlife preference/avoidance). Consider developed cells to be impassable, or totally unsuitable for wildlife corridors. Ideally, these impedances would be based on actual data.

MRLC (version 3)	**MRLC Class**	**Impedance**
Open water	11	150
Low intensity developed	21	No Data
High intensity residential	22	No Data
High intensity commercial/industrial	23	No Data
Bare rock/sand	31	150
Quarries/strip mines	32	500
Transitional barren	33	150
Deciduous forest	41	50
Evergreen forest	42	50
Mixed forest	43	50
Hay/pasture	81	150
Row crops	82	250
Urban grass	85	250
Woody wetlands	91	100
Emergent herbaceous wetlands	92	150
No Data	0, NoData	No Data

* Increase impedance of pine forest on Eastern Shore since they are likely to be planted (or at least managed) loblolly pine, with low structural and floristic diversity. Put impedance midway between deciduous forest and hay/pasture (100). Add 50 to impedance calculated above for class 42 on Eastern shore. Save final grid as `up_mrlc_imped`.

* In future versions, increase impedance of all evergreen forest somewhat (as in previous models). Usually lacks herbaceous layer because of needle-caused acidic soil.

Give forested wetlands (FO) that are temporarily flooded (A) an impedance of 50.

* From `NWI_MD.shp`, select ([Class] = "FO") and ([Water_reg] = "A_").
* Convert to grid `FOA`, with values 1, No Data.
* Reclassify land cover (`md_10mi_lc`) to forested wetland boolean grid.
* Select NWI FOA cells that are also classified as forested wetland in MRLC, and give impedance value of 50. Elsewhere = No Data.

Riparian forest impedance

* Reduce impedance of forest cells adjacent to water.
* Create grid combining OP streams and MRLC shorelines. First, from OP stream coverage, removed stream order = 50 (lake or pond shoreline) and 49 (drainage ditch)
* Converted selected set to grid, with same cell size and map extent as MRLC v3
* Reclassified grid so 1=stream, 0 elsewhere. Save as OP_strm_grid
* Since MOP stream data did not always correspond positionally with water in MRLC, it was combined with MRLC water.
* Compute distance from water
* Subtract 25 from impedance of forest cells adjacent to water.

Interior forest impedance

* Subtract 13 from impedance if forest is at least 300 ft from edge (implemented in final impedance step). This reflects added suitability for interior forest dwelling species, although edge species like deer, quail, bobcat, etc., would prefer edge habitat.

Proximity to urban development impedance

* Urban development is a source of disturbance, including runoff, pollutants, microclimate changes, noise, human disturbance, harassment of wildlife by pets, exotic species, etc. (Brown et al, 1990). We considered this disturbance effect to fall off with the inverse of distance from the source.
* From MRLC v3 (grid `md_10mi_lc`), calculate distance from high-intensity development.
* Convert distance from high-intensity development to impedance values. Save grid as `highint_imped`, where `[value]` is the addition to impedance:

Distance (cells)	Distance (ft)	Disturbance intensity	Add to impedance
0	0	2000	No Data (N/A)
1	117	1000	950
sqrt(2)	165	568	518
2	234	262	212
sqrt(5)	261	184	134
	300	50	0

* From MRLC v3 (grid md_10mi_lc), calculate distance from low-intensity development
* Convert distance from high-intensity development to impedance values. Save grid as `lowint_imped`, where `[value]` is the addition to impedance:

Distance (cells)	Distance (ft)	Disturbance intensity	Add to impedance
0	0	1000	No Data (N/A)
1	117	500	450
sqrt(2)	165	284	234
2	234	131	81
sqrt(5)	261	92	42
	300	50	0

* Combine impedances by selecting maximum value.

+ `Grid: urbprox_imped = max(highint_imped, lowint_imped)`

Road impedance

* Assign primary state roads and interstate highways (grid Primary_rds) an impedance value of 5000, since major roads are significant barriers. Save grid as pri_rd_imp.
* Assign secondary state roads (grid secondary_rds) an impedance value of 1000. Save grid as sec_rd_imp.
* Assign county roads (grid county_rds) an impedance value of 500. Save grid as cnty_rd_imp.
* Merge above three impedance layers (primary roads, secondary roads, and county roads).
* Extract bridges from SHA roads, and assign an impedance value of 300. Bridges are a source of disturbance, but can be passed under. Since they don't overlay road lines exactly, use 150 ft buffer.
  + ArcView: Select `[layer] = "RD_BRG"`. Save as `sha_bridges.shp`.
  + `Arc: shapearc sha_bridges bridges`
  + `Arc: build bridges line`
  + `Arc: buffer bridges bridge_buff # # 150 .001 line`
  + `Arc: polygrid bridge_buff brg_buff_grid inside`
  + `Grid: bridge_imp = con(brg_buff_grid, 300) * con(rd_imp1, 1)`
* Merge road impedance grids (bridges, primary roads, secondary roads, county roads). Save as road_imped (values 5000 = primary state roads and interstate highways; 1000 = secondary state roads; 500 = county roads; 300 = bridges; No Data = elsewhere).
  + `Grid: road_imped = merge(bridge_imp, rd_imp1)`

Offshore water impedance

* Set offshore water (water more than 500 ft from shore) to No Data, elsewhere to 0. Distance of 500 ft was picked arbitrarily. Add to other impedance grids.
* Create mask grid (`mrlc_nodata`) where No Data = bridges or other misleading water breaks, 0 elsewhere. Add to other impedance grids.

Slope impedance

* Areas of moderate or steep slope are more difficult to traverse. Ridgelines and valleys make good natural corridors.
* Reclassify `e:\data\DEM\slope_pct` to `slope_imped`:

Slope (%)	Add to impedance
0-8	0
9-15	2
16-25	5
>25	10

Protected land impedance

* Subtract 5 from impedance where land is protected, to reflect more favorable management.

Hub impedance

* Hubs are defined as blocks of suitable habitat, and would serve as favorable nodes in the network. Assign impedance according to ecological ranking (reclassify hub_tiers), and save as hub_imped.

Hub category	Subtract from impedance
1	6
2	4
3	2
non-hub (No Data)	0

Merge impedances to create overall landscape impedance.

* Give bridges impedance calculated earlier, other developed cells No Data; elsewhere overlay road impedance over FOA impedance and MRLC impedance:

  + `Grid: road_mrlc_imp = merge(bridge_imp, (merge(road_imped, foa_imped, up_mrlc_imped) + con(urbprox_imped >= 0, 0)))`

* Add impedances

  + `Grid: upland_imped = road_mrlc_imp - foradjwat_imp - con(e:\data\interior_forest_2\dist_wdedge >= 300, 13, 0) + urbprox_imped + slope_imped - (e:\data\protected_lands_2\all_protected * 5) - hub_imped + offshore_imp + mrlc_nodata + con(..\study_boundary\gi5_bnd_grd == 1, 0)`

Create impedance of 0 for upland core areas

* `Grid: upland_imp2 = con(isnull(upland_cores), upland_imped, 0)`

- Least-cost paths

Select a point within upland_cores

* Did manually in ArcView, since centroids can fall outside polygon.
* Convert to grid `up_core_pts`

Give points a unique ID

* `Grid: up_pts_each = regiongroup(up_core_pts, #, eight)`
* Convert to shapefile `up_pts_each.shp`.

Calculate x & y coordinates of these points. In ArcView, add script `View.AddXYCoordToFTab`. Adds X and Y coordinates of features to shapefile attribute table. Join these to up_pts_each, create fields `x-ft` and y-ft, and calculate these equal to the joined shapefile point coordinates (integer values).

For each large core point, connect to surrounding large core points within 50,000 ft.

* `Grid: &run auto_find_paths`
* `Grid: &run merge_paths`

Inspect, and eliminate LCP's that don't make sense.
* Arc: Convert to line coverage (gridline)
* ArcView: remove pathways connecting points other than those in core areas, etc.

" LCP's for wetland wildlife

- Core areas

Link core wetlands with natural waterways and wetlands. Esp. if similar types. Salt marshes will also be linked by aquatic system (Chesapeake Bay, Chincoteague Bay).

Select unmodified NWI wetlands at least 100 ac within top-ranked third of hubs.

- Impedance

Land cover impedance (`wetl_mrlc_imp`)

MRLC (version 3)	MRLC Class	Impedance
Open water	11	150
Low intensity developed	21	No Data
High intensity residential	22	No Data
High intensity commercial/industrial	23	No Data
Bare rock/sand	31	225
Quarries/strip mines	32	650
Transitional barren	33	275
Deciduous forest	41	225
Evergreen forest	42	225

Mixed forest	43	225
Hay/pasture	81	250
Row crops	82	325
Urban grass	85	325
Woody wetlands	91	50
Emergent herbaceous wetlands	92	50
No Data	0, NoData	No Data

Wetland impedance (`wetl_wetl_imp`)

* WSSC (grid `wssc`) = impedance of 25
* Unmodified wetlands from NWI (grid `wetland_unmod`) = impedance of 50
* Elsewhere = No Data.
* Merge WSSC and NWI impedances.

Riparian impedance (`wetl_rip_imp`)

* Create grid combining OP streams and MRLC shorelines
  + Grid combining OP streams and MRLC shorelines was done for upland impedance.
  + Remove small isolated patches (which are either ponds or classification errors). Patches of water <= 5 cells, or 68593 ft^2, were removed:
  + Select only water cells adjacent to land:
* Determine riparian distance
  + Reclassified MRLC (`Md_10mi_lc`) to forest, wetlands, and water = NoData; elsewhere = 1 (i.e., value other than NoData). Saved as `non_wdswet`.
  + Calculate distance of each forest, wetlands, and water cell to the nearest non-forest, wetlands, or water cell.
  + Calculate distance of each stream or shoreline cell to the nearest non-forest, wetlands, or water cell.
* Convert distance of each stream or shoreline cell to the nearest non-forest, wetlands, or water cell to impedances. Give

unbuffered water cells (adjacent to developed, barren, agricultural, or grass land cover) the impedance of open water (150). Reduce impedance of buffered cells. Give water cells buffered at least 300 ft (417 feet between cell centers) half that impedance (75), and cells buffered 1 cell (234 feet between cell centers) an impedance of 100. Use linear stretch between 234 ft and 417 ft. Save as `wetl_rip_imp`.

Riparian distance (ft)	**Riparian impedance**
<234	150
234	100
261	96
331	87
351	84
370	81
417	75

Interior forest impedance

* Same as for upland

Road impedance

* Same as for upland

Proximity to urban development impedance

* Same as for upland

Offshore water impedance

* Double impedance (add 150) to water more than 500 ft from shore.

Slope impedance

* Same as for upland

Protected land impedance

* Same as for upland

Hub impedance

* Same as for upland

Merge impedances to create overall landscape impedance.

* `Grid: &sv .ui = e:\data\Green_Infrastructure_v5\wildlife_upland\`
* Give bridges impedance calculated earlier, other developed cells No Data; elsewhere overlay road impedance over wetland, riparian, and land cover impedances:

  + ```
    Grid: road_mrlc_imp =
    merge(%.ui%bridge_imp,
    (merge(%.ui%road_imped, wetl_wetl_imp,
    wetl_rip_imp, wetl_mrlc_imp) +
    con(%.ui%urbprox_imped >= 0, 0)))
    ```

* Add impedances

  + ```
    Grid: wetland_imped = road_mrlc_imp -
    con(e:\data\interior_forest_2\dist_wdedge
    >= 300, 13, 0) + %.ui%urbprox_imped +
    %.ui%slope_imped -
    (e:\data\protected_lands_2\all_protected *
    5) - %.ui%hub_imped + wetl_offs_imp +
    con(..\study_boundary\gi5_bnd_grd == 1, 0)
    ```

Create impedance of 0 for wetland core areas

* ```
  Grid: wetland_imp2 = con(isnull(wetland_cores),
  wetland_imped, 0)
  ```

- Least-cost paths

Select a point within wetland_cores

* Did manually in ArcView, since centroids can fall outside polygon. For wetlands, select riparian wetlands and large wetlands (not small isolated wetlands).
* Convert to grid `wet_core_pts`

Give points a unique ID
  ```

* `Grid: wet_pts_each = regiongroup(wet_core_pts, #, eight)`
* Convert to shapefile `wet_pts_each.shp`.

Calculate x & y coordinates of these points. In ArcView, add script `View.AddXYCoordToFTab`. Adds X and Y coordinates of features to shapefile attribute table. Join these to `wet_pts_each`, create fields x-ft and `y-ft`, and calculate these equal to the joined shapefile point coordinates (integer values).

For each large core point, connect to surrounding large core points within 50,000 ft.

* `Grid: &run auto_find_paths`
* `Grid: &run merge_paths`

Inspect, and eliminate LCP's that don't make sense

* Arc: Convert to line coverage (gridline)
* ArcView: remove pathways connecting points other than those in core areas, etc.

" LCP's for fresh-water aquatic wildlife

- Should protect waterways by buffering all streams, and protecting water quality. For this analysis, link aquatic core areas.

- Core areas

All aquatic areas used to define hubs, if they are within top tier of hubs. These include upper Potomac, Youghiogheny wild river section, brook trout streams, blackwater streams, MBSS complementary streams, stream reaches containing aquatic species of concern, and streams within watersheds with high anadromous fish scores.

Streams with high biotic integrity within top-ranked third of hubs

* Benthic Macroinvertebrate Index

+

+ The Benthic Macroinvertebrate Index score (field bent_110) was developed using Maryland Biological Stream Survey (MBSS), Targeted Watershed Project, and Rapid Bioassessment Program data. Comparable sampling and scoring methods were used to develop an index from these programs. If there were multiple sites on the reach, the field bent_110 of gr_in_mb.dbf was obtained by averaging their IBI scores and converting back to a value between 1 and 10 (the IBI is the avg of several metrics and is often not an integer.)

+ Create grid of Benthic Macroinvertebrate Index scores for stream cells: `([Riparian_grid] * [Prox_mbss_2 . Bent_100])`

+ Save grid as `mbss_bent`.

+ Select `mbss_bent >= 80`.

* Fish Index of Biotic Integrity

  + The Fish Index of Biotic Integrity (IBI) score (field fish_110) was developed from Maryland Biological Stream Survey and Targeted Watershed Project data. Fish were collected using the same methods in both of these programs. If there were multiple sites on the reach, the field fish_110 of gr_in_mb.dbf was obtained by averaging their IBI scores and converting back to a value between 1 and 10 (the IBI is the avg of several metrics and is often not an integer.)

  + Create grid of Fish IBI scores for stream cells: `([Riparian_grid] * [Prox_mbss_2 . Fish_100])`.

  + Save grid as `mbss_fish`.

  + Select `mbss_fish >= 80.`

* Select high IBI streams within top-ranked third of hubs.

  + Spatial Analyst: Combine `mbss_fish >= 80 or mbss_bent >= 80.` Save as Boolean grid `high_IBI_strm`.

  + `Grid: tophub_hi_ibi = con(high_IBI_strm == 1, 1) * con(e:\data\Green_Infrastructure_v5\hub_rank\hub_tiers == 1, 1)`

Combine aquatic core areas.

* `Grid: aquatic_core1 = con(isnull(tophub_aq), 0, tophub_aq) or con(isnull(tophub_hi_ibi), 0, tophub_hi_ibi)`

* `Grid: aquatic_cores = con(aquatic_core1 == 1, 1)`

- Impedance

Land cover impedance (`aq_mrlc_imped`):

MRLC (version 3)	**MRLC Class**	**Impedance**
Open water	11	100
All other classes	21-92	No Data
No Data	0, NoData	No Data

Wetland impedance (`aq_wetl_imped`)

* Assign permanently flooded (`[Water_reg] = "H_"`), unmodified wetlands from NWI an impedance of 150, if not classified as water on MRLC. Not very many of these.

Riparian impedance (`aq_rip_imped`)

* Create grid combining OP streams and MRLC shorelines
    + Calculated for wetland impedance
* Determine riparian distance
    + Calculated for wetland impedance
* Convert distance of each stream or shoreline cell to the nearest non-forest, wetlands, or water cell to impedances. Streams without riparian buffers (cells adjacent to developed, barren, agricultural, or grass land cover) were given a high impedance (twice that of open water alone). Reduce impedance of buffered cells to reflect bank stabilization, shading of water (thus moderating water temperature), sediment and nutrient trapping, increased instream habitat and detritus, etc. Give water cells buffered at least 300 ft (417 feet between cell centers) 1/4 the impedance (25), and cells buffered 1 cell (234 feet between cell centers) half the impedance (50). Use linear stretch between 234 ft and 417 ft. Save as `wetl_rip_imp`.

Riparian distance (ft)	**Riparian impedance**
<234	200

234	50
261	46
331	37
351	34
370	31
417	25

Aquatic community impedances

* Data source: MBSS
* MBSS data could be linked to MBSS stream reaches, but not MOP streams. Accordingly, assign MBSS stream reaches and aquatic indices to MOP streams (as far as possible).
    +
    + Stream reach file: `v:\streams\mdstream` (1:250,000 scale)
    + Database file of aquatic indices by stream reach: `gr_in_mb.dbf` (dBASE format)
    + The stream reach file was 1:250,000 scale, and does not overlay MOP streams exactly. To assign stream reach ID's and MBSS data to stream coverages and grids derived from MOP, used two steps.
    + Created grid with each cell assigned to the nearest stream reach (Spatial Analyst, Assign Proximity). Saved grid as `prox_mbss_str`.
    + Then, removed cells further than 700 ft from an MBSS stream reach, so that unsampled tributaries and ponds would not be assigned MBSS data. 700ft was chosen after examination of discrepancies between the two stream coverages.
    + Buffered MBSS stream coverage a distance of 700 ft. Saved as `Mbss_mdstr_700ft_buffer.shp`
    + Convert to grid `Buff700ft_grd`
    + `Grid: prox_mbss_2 = con(buff700ft_grd, prox_mbss_str)`

+ Link MBSS indices to stream reach.

  - Joined dbase table `gr_in_mb.dbf` to `prox_mbss_2`
  - Created 3 new fields, to give integer values for indices:
    - x [ASCI] = [Ret_r] (range 0-10)
    - x [fish_100] = [fish_110] * 10 (range 0-100)
    - x [bent_100] = [bent_110] * 10 (range 0-100)

* Benthic Macroinvertebrate Index

  + The Benthic Macroinvertebrate Index score (field `bent_110`) was developed using Maryland Biological Stream Survey (MBSS), Targeted Watershed Project, and Rapid Bioassessment Program data. Comparable sampling and scoring methods were used to develop an index from these programs. If there were multiple sites on the reach, the field `bent_110` of `gr_in_mb.dbf` was obtained by averaging their IBI scores and converting back to a value between 1 and 10 (the IBI is the average of several metrics and is often not an integer.)
  + Create grid of Benthic Macroinvertebrate Index scores for stream cells:
    - `([Riparian_grid] * [Prox_mbss_2 . Bent_100])`
    - Save grid as `mbss_bent`
  + Convert to impedance:
    - [`bent_110`] = 8-10 : good; subtract 5 from impedance
    - [`bent_110`] = 4-7.9 : poor to fair; subtract 0 from impedance
    - [`bent_110`] = 1-3.9 : very poor; add 5 to impedance
  + Reclassify grid `mbss_bent`: 80-100 to -5; 40-79, 0, NoData to 0; 1-39 to 5
  + Save grid as `bent_imped`

* Fish Index of Biotic Integrity
  + The Fish Index of Biotic Integrity (IBI) score (field `fish_110`) was developed from Maryland Biological Stream Survey and Targeted Watershed Project data. Fish were collected using the same methods in both of these programs. If there were multiple sites on the reach, the field `fish_110` of `gr_in_mb.dbf` was obtained by averaging their IBI scores and converting back to a value between 1 and 10 (the IBI is the avg of several metrics and is often not an integer.)
  + Create grid of Fish IBI scores for stream cells:
    - `([Riparian_grid] * [Prox_mbss_2 . fish_100])`
    - Save grid as `mbss_fish`
  + Convert to impedance:
    - [`fish_110`] = 8-10 : good; subtract 5 from impedance
    - [`fish_110`] = 4-7.9 : poor to fair; subtract 0 from impedance
    - [`fish_110`] = 1-3.9 : very poor; add 5 to impedance
  + Reclassify grid `mbss_fish`: 80-100 to -5; 40-79, 0, NoData to 0; 1-39 to 5
  + Save grid as `fish_imped`
* Aquatic Species of Concern Index
  + The Aquatic Species of Concern Index (field `ret_r`) was developed using Wildlife and Heritage division listing information for amphibian, fish, crayfish and mussel species. Marty Hurd did not average this variable; if there were 3 sites on the reach, he scored it with the site that had the best combination of rare species. The index varied between 1-10:

Aquatic Species of Concern Index	**Found at site**
10	Two or more rare / endangered species present.
9	One or more rare / endangered species present.

8	Three or more threatened/candidate (for listing) species.
7	Two or more threatened/candidate (for listing) species.
6	One threatened/candidate (for listing) species.
1	Sampled, but none found.
0	Not sampled

+ Create grid of ASCI scores for stream cells:
    - `([Riparian_grid] * [Prox_mbss_2 . Asci])`
    - Save grid as `mbss_asci_gr`
+ Convert to impedance:
    - `[ret_r]` = 8-10 : subtract 10 from impedance
    - `[ret_r]` = 6-7 : subtract 5 from impedance
    - `[ret_r]` < 6 : subtract 0 from impedance
+ Reclassify grid `mbss_asci_gr`: 1, NoData to 0; 6-7 to -5; 8-10 to -10
+ Save grid as `asci_imped`

* Cumulative effect of MBSS data
    + The three MBSS indicators Benthic Macroinvertebrate Index, Fish IBI, and Aquatic Species of Concern Index could vary stream impedance by -20 to +10

Brook trout waters

* Subtracted 5 from impedance for brook trout streams

Fish blockages

* Used Maryland fish passage program database. Only streams used by anadromous fish were investigated. Mostly on Coastal Plain.
* Removed blockage points where `[Comments]` indicated "no blockage" or that the blockage had been removed. Also removed points where a completion date was indicated (where a fish passage project had been completed). Converted to grid with impedance values according to field `[struct_typ]` (structure type codes):

Structure code	Structure type	Impedance
DM	DAM	10000
PC	PIPE CULVERT	500
F	FISHWAY	200
GW	GAGING STATION WEIR HAVING VERTICAL DROP	2000
G	GABION	5000
PX	PIPELINE CROSSING	200
AC	ARCH CULVERT	500
BC	BOX CULVERT	500
C	RAISED CULVERT PRESENT; TYPE NOT DETERMINED	2000
TG	TIDE GATE	2000
BD	BEAVER DAM	500
LD	LOG/DEBRIS	200
OT	OTHER	5000
BR	BRIDGE	50
	(no data)	5000

* Assigning blockages to areas of water was difficult, since the points did not coincide with water delineation exactly. Assumed 500 ft positional uncertainty, after examining data.
* First, add script `WizardBuffer.FINISH`. Calculate 500 ft buffers around blockage points, retaining field [`impedance`].
* Convert to grid `blockage_buff`, using [`impedance`] as cell value.
* Combine water cells:
    +
    ```
    Grid: aq_cells =
    con(isnull(aq_wetl_imped), 0, 1) or
    con(isnull(aq_mrlc_imped), 0, 1) or
    con(isnull(..\wildlife_wetland\riparian_gr
    id), 0, 1)
    ```
* Intersect with blockage buffers:

+ `Grid: aq_block = con(aq_cells == 1, 1) * blockage_buff`

* Create unique regions, and calculate area in number of cells:

+ `Grid: aq_reg = regiongroup(con(aq_block, 1), #, eight)`

+ `Grid: aqreg_cellnum = int(zonalarea(aq_reg) / 13718.43)`

* Spread the blockage impedance over the cells within the buffer:

+ `Grid: fishblock_im1 = int(blockage_buff / aqreg_cellnum)`

+ `Grid: fishblock_imp = con(isnull(fishblock_im1), 0, fishblock_im1)`

Proximity to urban development impedance

* Same as for upland, except replace NoData values with data.

+ Spatial Analyst: Reclassify MRLC to value 2000 for high intensity developed (class 22-23) and value 1000 for low intensity developed (class 21). Save as `urban_imp1`.

+ `Grid: aq_urb_imped = con(isnull(..\wildlife_upland\urbprox_imped), urban_imp1, ..\wildlife_upland\urbprox_imped)`

Protected land impedance

* Same as for upland

Hub impedance

* Same as for upland

Merge impedances to create overall landscape impedance.

* `Grid: &sv .ui = e:\data\Green_Infrastructure_v5\wildlife_upland\`

* `Grid: aquatic_imp1 = merge(aq_rip_imped, aq_mrlc_imped, aq_wetl_imped, con(e:\data\streams\upper_potomac == 1, 100)) +`

```
bent_imped + fish_imped + asci_imped +
brk_trout_imp + fishblock_imp + aq_urb_imped -
(e:\data\protected_lands_2\all_protected * 5) -
%.ui%hub_imped
```

* Reclassify values less than 1 to 1:

  + `Grid: aquatic_imped = con(aquatic_imp1 < 1, 1, aquatic_imp1)`

  + `Grid: kill aquatic_imp1 all`

Create impedance of 0 for aquatic core areas

* `Grid: aquatic_imp2 = con(isnull(aquatic_cores), aquatic_imped, 0)`

- Least-cost paths

Select a point within aquatic core areas

* Did manually in ArcView, since centroids can fall outside polygon.

* Convert to grid `aq_core_pts`

Give points a unique ID

* `Grid: aq_pts_each = regiongroup(aq_core_pts, #, eight)`

* Convert to shapefile `aq_pts_each.shp`.

Calculate x & y coordinates of these points. In ArcView, add script `View.AddXYCoordToFTab`. Adds X and Y coordinates of features to `aq_pts_each.shp` attribute table. Join these to `aq_pts_each`, create fields `x-ft` and `y-ft`, and calculate these equal to the joined shapefile point coordinates (integer values).

For each large core point, connect to surrounding large core points within 50,000 ft.

* `Grid: &run auto_find_paths`

* `Grid: &run merge_paths`

Inspect, and eliminate LCP's that don't make sense.

* Arc: Convert to line coverage (gridline)

* ArcView: remove pathways connecting points other than those in core areas, etc.

" There was one hub that was not assigned LCP connections: Fair Hill Natural Resource Area.

- Since it was mostly upland, and its stream (Big Elk Creek) went through an urban area (Elkton), focused on possible upland connections.
- Created shapefile with single point, on Big Elk Creek at junction with a tributary. Convert to ARC point coverage `Fair_hill_pt` and grid `Fair_hill_ptg`.
- `Grid: &run find_paths_between_points.aml`
- Convert LCP's to line coverage, and then shapefile `fair_hill_lcp.shp`.

" Combination of LCPs

- Merge upland (incl. Fair Hill), wetland, and aquatic LCP's (ArcView Merge Themes)
- Convert to grid `all_lcp` (values 1, NoData)

" Corridor and node identification

- `&run corridors.aml`
- `&run nodes.aml`

" Separate corridors and nodes internal and external to top tiered hub areas

- Create grid of top tier hubs plus their internal gaps
- Separate LCP's as internal or external to top tier hubs. LCPs that are entirely adjacent to top tier hubs are also considered as internal.
- Separate corridors as internal or external to top tier hubs.
- Determine which node groupings are adjacent to external corridors. Rest are considered part of hub buffer.

! **Corridors linking second and third-tier hubs**

" Least cost paths (LCP) for upland wildlife

- Core areas
    # Reclass MRLC v3 to upland forest (41-43 to 1) or elsewhere (to 0)

- Select upland forest at least 300' from non-forest (forested wetlands count as forest)
- Select upland interior forest within lower-ranked 2/3 of hubs.
- Select those groupings at least 100 ac, and save as up_lowercores

- Impedance
  - Same as impedance for top-tier hub linkages, but create impedance of 0 for all upland core areas

- Least-cost paths
  - Select points within up_lowercores where lower tier hubs aren't connected to top tier network. Also select points in top tier cores near lower tier cores.
    - Did manually in ArcView, since centroids can fall outside polygon.
    - Convert to grid `up_lcore_pts`
  - Give points a unique ID
    - `Grid: up_lc_pts_ea = regiongroup(up_lcore_pts, #, eight)`
    - Convert to shapefile `up_lc_pts_ea.shp`.
  - Calculate x & y coordinates of these points. In ArcView, add script `View.AddXYCoordToFTab`. Adds X and Y coordinates of features to shapefile attribute table. Join these to `up_lc_pts_ea`, create fields `x-ft` and `y-ft`, and calculate these equal to the joined shapefile point coordinates (integer values).
  - For each large core point, connect to surrounding large core points within 50,000 ft.
    - `Grid: &run auto_find_paths`
    - `Grid: &run merge_paths`
  - Remove pathways that duplicate top-tier linkages (where they overlap top tier hubs, corridors, or nodes)
  - Inspect, and eliminate LCP's that don't make sense.
    - Arc: Convert to line coverage (gridline).
    - ArcView: Convert to shapefile, and manually remove redundant pathways.

" LCP's for wetland wildlife

- Core areas
  # Select unmodified NWI wetlands at least 100 ac within lower-ranked 2/3 of hubs.

- Impedance
  # Same as impedance for top-tier hub linkages, but create impedance of 0 for all wetland core areas.

- Least-cost paths
  # Select points within up_lowercores where lower tier hubs aren't connected to top tier network. Also select points in top tier cores near lower tier cores.
    * Did manually in ArcView, since centroids can fall outside polygon.
    * Convert to grid `wet_lcore_pts`
  # Give points a unique ID
    * `Grid: wet_lc_pts_ea = regiongroup(wet_lcore_pts, #, eight)`
    * Convert to shapefile `wet_lc_pts_ea.shp`.
  # Calculate x & y coordinates of these points. In ArcView, add script `View.AddXYCoordToFTab`. Adds X and Y coordinates of features to shapefile attribute table. Join these to `wet_lc_pts_ea`, create fields `x-ft` and `y-ft`, and calculate these equal to the joined shapefile point coordinates (integer values).
  # For each large core point, connect to surrounding large core points within 50,000 ft.
    * `Grid: &run auto_find_paths`
    * `Grid: &run merge_paths`
  # Remove pathways that duplicate top-tier linkages (where they overlap top tier hubs, corridors, or nodes)
    * `Grid: wet_lcore_lc2 = wet_lcore_lcp * con( isnull(..\top_hub_tier_linkages\Nodes_corr5) and isnull(..\hub_rank\Tophubs_nogap) , 1)`

Inspect, and eliminate LCP's that don't make sense.

*   Arc: Convert to line coverage (gridline).

*   ArcView: Convert to shapefile, and manually remove redundant pathways.

"   LCP's for aquatic wildlife

-     Core areas

All aquatic areas used to define hubs, if they are within lower tiers of hubs. These include upper Potomac, Youghiogheny wild river section, brook trout streams, blackwater streams, MBSS complementary streams, stream reaches containing aquatic species of concern, and streams within watersheds with high anadromous fish scores.

Streams with high biotic integrity within top-ranked third of hubs

*   Spatial Analyst: Combine mbss_fish >= 80 or mbss_bent >= 80. Save as Boolean grid `high_IBI_strm`.

*   `Grid: lowhub_hi_ibi = con(..\wildlife_aquatic\high_IBI_strm == 1, 1) * con(..\hub_rank\hub_tiers > 1, 1)`

Combine aquatic core areas.

*   `Grid: aquatic_core1 = con(isnull(lowhub_aq), 0, lowhub_aq) or con(isnull(lowhub_hi_ibi), 0, lowhub_hi_ibi)`

*   `Grid: aq_low_cores = con(aquatic_core1 == 1, 1)`

*   `Grid: aq_cores = merge(aq_low_cores, ..\wildlife_aquatic\aquatic_cores)`

-     Impedance

Same as impedance for top-tier hub linkages, but create impedance of 0 for all wetland core areas.

-     Least-cost paths

Select points within `up_lowercores` where lower tier hubs aren't connected to top tier network. Also select points in top tier cores near lower tier cores.

* Did manually in ArcView, since centroids can fall outside polygon.
* Convert to grid `aq_lcore_pts`

Give points a unique ID

* `Grid: aq_lc_pts_ea = regiongroup(aq_lcore_pts, #, eight)`
* Convert to shapefile `aq_lc_pts_ea.shp`.

Calculate x & y coordinates of these points. In ArcView, add script `View.AddXYCoordToFTab`. Adds X and Y coordinates of features to shapefile attribute table. Join these to `aq_lc_pts_ea`, create fields `x-ft` and `y-ft`, and calculate these equal to the joined shapefile point coordinates (integer values).

For each large core point, connect to surrounding large core points within 50,000 ft.

* `Grid: &run auto_find_paths` /* note for future - don't eliminate small pathways
* `Grid: &run merge_paths`

Remove pathways that duplicate top-tier linkages (where they overlap top tier hubs, corridors, or nodes)

* `Grid: aq_lcore_lcp2 = aq_lcore_lcp * con( isnull(..\top_hub_tier_linkages\ Nodes_corr5) and isnull(..\hub_rank\Tophubs_nogap) , 1)`

Inspect, and eliminate LCP's that don't make sense.

* Arc: Convert to line coverage (gridline).
* ArcView: Convert to shapefile, and manually remove redundant pathways.

" Other LCP's - where hubs were not linked to the network using previous methods, because of insufficient core area or linkage potential.

- Impedance and core areas

Merge aquatic, wetland, and upland impedances.

* `Grid: other_imp1 = min( con(isnull(up_lcore_imp), 99999, up_lcore_imp), con(isnull(wet_lcore_imp), 99999, wet_lcore_imp), con(isnull(aq_lcore_imp), 99999, aq_lcore_imp) )`

- # Give all hubs impedance of 1, and core areas calculated previously an impedance of 0.
  - * `Grid: hubs = con(..\hub_rank\hub_tiers, 1)`
  - * `Grid: other_cores = merge(up_cores, wet_cores, aq_cores)`
  - * `Grid: other_imp2 = merge( con(cores, 0), hubs, other_imp1 )`
- # With impedance values of 99999, the cost distance mapping took too long. Replace this value with No Data.
  - * `Grid: oth_lcore_imp = con(other_imp2 < 9999, other_imp2)`

- Least-cost paths
  - # Points were selected manually in those hubs not yet linked to the network, unless they were primarily salt marsh or aquatic, and bordering the Chesapeake or Chincoteague Bay. These latter exceptions were considered linked by the bay. Also added points in nearby hubs to be linked to. Saved as `other_lcore_pts.shp`.
  - # Convert to grid `oth_lcore_pts`
  - # Give points a unique ID
    - * `Grid: oth_lc_pts_ea = regiongroup(oth_lcore_pts, #, eight)`
    - * Convert to shapefile `oth_lc_pts_ea.shp`.
  - # Calculate x & y coordinates of these points. In ArcView, add script `View.AddXYCoordToFTab`. Adds X and Y coordinates of features to shapefile attribute table. Join these to `oth_lc_pts_ea`, create fields `x-ft` and `y-ft`, and calculate these equal to the joined shapefile point coordinates (integer values).
  - # For each large core point, connect to surrounding large core points within 50,000 ft.
    - * `Grid: &run auto_find_paths` /* note for future - don't eliminate small pathways
    - * `Grid: &run merge_paths`
  - # Remove pathways that duplicate top-tier linkages (where they overlap top tier hubs, corridors, or nodes)

* `Grid: oth_lcore_lc2 = oth_lcore_lcp * con( isnull(..\top_hub_tier_linkages\Nodes_corr5) and isnull(..\hub_rank\Tophubs_nogap) , 1)`

Inspect, and eliminate LCP's that don't make sense.

* Arc: Convert to line coverage (gridline).
* ArcView: Convert to shapefile, and manually remove redundant pathways.

" Combination of LCPs

- Merge upland, wetland, aquatic, and other LCP's (ArcView Merge Themes)
- Convert to grid `all_lower_lcp` (values 1, NoData)

" Corridor and node identification

- `&run lower_tier_corridors.aml`
- `&run lower_tier_nodes.aml`

" Separate external lower tier corridors and nodes

- `Arc: w e:\data\Green_Infrastructure_v5\lower_hub_tier_linkages`
- `Grid: other = con(isnull(..\hub_rank\hub_tiers), 0, 1) or con(isnull(..\top_hub_tier_linkages\corr_external), 0, 1)`
- `Grid: lower_cor_ext = con(( con(isnull(lower_corr), 0, 1) and ( ^ other ) ), 1)`
- `Grid: other2 = other or con(isnull(lower_cor_ext), 0, 1) or con(isnull(..\top_hub_tier_linkages\node_external), 0, 1) or con(isnull(..\hub_buffer\hub_buffered), 0, 1)`
- `Grid: lnodes_ext = con( ( lnodes_corr4 and ( ^ other2 ) ), 1)`

! **Combine upper and lower tier corridors, nodes, and LCPs**

" `Grid: &sv top = e:\data\green_infrastructure_v5\top_hub_tier_linkages\`

" `Grid: &sv low = e:\data\green_infrastructure_v5\lower_hub_tier_linkages\`

" `Grid: all_corridors = merge(%top%corridors, %low%lower_corr)`

" `Grid: all_cornnode = merge(%top%nodes_corr5, %low%lnodes_corr4)`

" `Grid: all_lcp = merge(%top%all_lcp, %low%all_lower_lcp)`

" `Grid: corrnode_ext = all_corrnode * con(isnull(e:\data\green_infrastructure_v5\hub_rank\hub_tiers), 1)`

" `Grid: all_corr_ext = all_corridors * con(isnull(e:\data\green_infrastructure_v5\hub_rank\hub_tiers), 1)`

" `Grid: all_lcp_ext = all_lcp * con(isnull(e:\data\green_infrastructure_v5\hub_rank\hub_tiers), 1)`

! **Hub buffers**

" Recalculate internal hub gaps. Some of previously calculated hub gaps fell within hubs outside Maryland, that had since been dropped. Calculate the area of non-hub cell aggregations in acres, and discount area outside hubs (>10,000 ac)

- `Grid: e:\data\green_infrastructure_v5\restoration\hub_gaps = con( (zonalarea (regiongroup (con(isnull(e:\data\green_infrastructure_v5\hub_rank\hub_tiers), 1), #, four)) / 43560) < 10000, 1 )`

" Buffers may be needed around movement least cost paths, wetlands, and streams and shorelines. Identify these features within all (not just top tier) hubs, and buffer 550 ft (as with corridors). Minimize land use and energy gradients by buffering core areas and corridors with low-intensity land uses like commercial forest, pasture, agriculture. Possible link to Rural Legacy, ag easements, etc.?

- Create grid combining hubs and their internal gaps

  # `Arc: w e:\data\green_infrastructure_v5\hub_rank`

  # `Grid: hubs_nogaps = merge( con(hub_tiers, 1), e:\data\green_infrastructure_v5\restoration\hub_gaps )`

- LCP buffers

  # Already calculated as corridors (`corr_internal`) for top tier hubs (but not lower tier hubs).

- Wetland buffers

- # Previously separated forested and unforested wetlands. Select forested wetlands within hubs, and buffer 550 ft.
- # Select unforested wetlands within hubs, and buffer 325 ft.
- # Combine wetland buffers.

- Stream buffers - buffer streams within hubs 550 ft.

- Combine LCP, wetland, and stream buffers.

! **County feedback**

Maps of Green Infrastructure model output were reviewed by county planning and parks and recreation departments. Several dozen areas were suggested as additional inclusions, as either hubs or corridors. In most cases, these were county parks or other public lands missed by the model. If these areas contained at least 100 ac of contiguous natural area (forest, wetland, beach, etc.), or if they were adjacent to modeled hubs or corridors, they were added to the proposed network. Otherwise, they were not added. Other additions included stream or river valleys being targeted by counties for conservation and/or restoration, such as Watts Branch, Southwest Branch, Winters Run, Little Bennett Creek, Deer Creek, and the Monocacy River. Some riparian corridors were adjusted to retain entire stream valleys. For example, Deer Creek was buffered along its entire mainstem, amending the modeled corridor which jumped out of the riparian zone where the river passed through agriculture. Additions stemming from county comments totalled 34,947 ac (an increase of 1.32%).

Conversely, several areas were suggested for deletion. Most of these were areas that had been developed since the model source data was acquired. In a few other cases, proposed corridors were too heavily parcelized for feasible implementation, and alternative routes which were more protected were suggested. ADC street maps were also referenced to omit unfeasible corridors. Most of the 23 subtractions were in the fast-growing central and southern portions of the state. 9086 ac (0.34%) were subtracted from the model.

Further additions came from the Baltimore County greenway model (see Baltimore County Department of Environmental Protection and Resource Management, 1996). Areas identified as hubs or corridors by this model, as natural areas according to both MRLC and OP 1997 land use/land cover, and not identified by the Green Infrastructure model, were added to the proposed network. These additions were relatively minor (3553 additional ac, or 0.13%).

Finally, ecologically significant areas digitized by the Maryland DNR Heritage Division were added if they were adjacent to, but not entirely within, modeled hubs or corridors. These included Natural Heritage Areas (NHA), Wetlands of Special State Concern (WSSC) and 550 ft buffers, Habitat Protection Areas (HPA), Ecologically Significant Areas (ESA), and Geographic Areas of Particular Concern (GAPC). The ESA's, HPA's, and GAPC's were draft products at the time. Furthermore, not all areas containing observed rare species had been digitized (except the rough delineations of SSPRA's). The heritage areas totalled 189,798 ac, although some of these were buffers. 172,593 ac (91%) fell within GI hubs or corridors. Of the remainder, 11,649 ac (68%) were added to the proposed network, bringing the total to 184,242 ac (97%). The increase in GI area was 0.44%; some of this overlapped with additions from other sources. Heritage areas falling outside the network should still be considered for protection.

Maps containing these revisions were mailed to the planning departments of each county for further review. The final product was published in the The Maryland Atlas of Greenways, Water Trails and Green Infrastructure, 2000 Edition. The Green Infrastructure network published in this atlas was 43,604 ac (1.65%) larger than the GI model.

! References

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Appendix B

Data sources used to model Maryland's Green Infrastructure network

Data layer	Source	Scale	Horizontal positional accuracy	Time of ground condition	Additional caveats
U.S. Federal Region III Land Cover Data Set (MRLC), version 3	originally, U.S. Geological Survey, EROS Data Center. Reprojected by US EPA.	cell size 117.1257 ft	117.1257 ft	Primarily 1991-3	Classification accuracy assessment not done. Data appears generally accurate (for the time), except between row crops and hay/pasture. These were therefore combined for most GI analyses.
Maryland Land Cover Data Set (from MRLC, version 3)	U.S. Geological Survey, EROS Data Center.	cell size 117.1257 ft	117.1257 ft	Primarily 1991-3	same as above.
1997 Land Use/Land Cover for Maryland	Maryland Office of Planning	1:63,360	106 ft	1997	Prince George's and Anne Arundel counties were not complete at the time of initial GI analyses, so 1994 land use/ land cover was used for these. When PG and AA counties completed their review of 1997 LU/LC, this was used in later GI analyses. Because the minimum mapping unit was 10 acres, and 500 ft minimum width, this data set was only used as a supplement to MRLC.
1994 Land Use/Land Cover for Maryland	Maryland Office of Planning	1:63,360	30 m, although some polygons were worse	1994	Used for Prince George's and Anne Arundel counties while 1997 data was unavailable.
Maryland streams	Maryland Office of Planning	1:24,000	Approx. 40 ft	unknown	Developed by digitizing quad sheets; true first order streams are often missed

Data layer	Source	Scale	Horizontal positional accuracy	Time of ground condition	Additional caveats
Maryland wetlands	National Wetlands Inventory (NWI)	1:24,000	40 ft	1981-2	The minimum mapping unit ranges from 1 to 3 acres depending on the feature being interpreted. In general, this data set under estimates the amount of palustrine forested wetlands which are the most difficult class to interpret. Site specific evaluations are required for regulatory purposes.
Maryland roads	Maryland State Highway Administration	1:100,000	167 ft	1996-7	
Delaware roads	TIGER	1:100,000	167 ft	1992	
Virginia roads	TIGER	1:100,000	167 ft	1992	
Pennsylvania roads	Environmental Resources Research Institute	unknown	unknown	1997	
West Virginia roads	TIGER	1:100,000	167 ft	1992	
Wetlands of Special State Concern	Maryland Department of Natural Resources	1:24,000	40 ft	1981-2; updated 1997	Programmatic definition
Sensitive Species Project Review Areas	Maryland Department of Natural Resources	1:24,000	Boundaries are generalized	1991-7	Polygons generally encompass, but do not delineate, RTE sites and other regulated areas. Polygons are unattributed, and have limited utility.
Natural Heritage Areas	Maryland Department of Natural Resources	1:24,000	40 ft	1997-8	Programmatic definition
Ecologically Significant Areas, Geographic Areas of Particular Concern, and Habitat Protection Areas	Maryland Department of Natural Resources	unknown	unknown	1999	Incomplete at the time of use
Maryland county boundaries	Maryland Dept. of Natural Resources	1:24,000	40 ft	1997	Narrow slivers exist between Montgomery and PG county polygons and between Calvert and St. Mary's counties

Data layer	Source	Scale	Horizontal positional accuracy	Time of ground condition	Additional caveats
Maryland 8-digit watershed boundaries	Maryland Dept. of Natural Resources	1:24,000	40 ft	1997	1997 revised DNR designated second level or sub-watershed level which encompasses 138 watersheds. The Chesapeake Bay (which is not a watershed) has been subdivided into three hydrologic units for purposes related to DNR responsibilities. A fourth hydrologic unit is the Atlantic Ocean. The watershed boundaries end artificially at the state boundary.
Maryland 12-digit watershed boundaries	Maryland Dept. of Natural Resources	1:24,000	40 ft	1997	
Anadromous and Semi-anadromous Fish Index	Maryland Dept. of Natural Resources	Maryland 8-digit watershed	watershed file accurate to 1:24,000	unknown	This index is derived from fish information that is collected with gear that is biased toward juvenile fish communities. Data on adult populations would be a valuable addition to these analysis, as it would allow assessment of the river in terms of the entire fish population.
MBSS stream reaches	Maryland Dept. of Natural Resources	1:250,000	unknown; (if adhering to NMAS, 417 ft)	unknown	Since scale is so small, these reaches were assigned to the nearest OP stream (see methodology)
MBSS biological, water quality, and physical habitat data	Maryland Dept. of Natural Resources		100 ft	1994-7	Field data acquired at sample sites. Sample sites do not cover entire state, but randomly selected 1st-3rd order nontidal stream reaches.
MBSS catchments	Maryland Dept. of Natural Resources		100 ft	1994-7	Digitized catchments upstream of sample sites
MBSS Benthic Macroinvertebrate Index	Maryland Dept. of Natural Resources		100 ft	1994-7	Sample sites do not cover entire state, but randomly selected 1st-3rd order nontidal stream reaches.
MBSS Fish Index of Biotic Integrity	Maryland Dept. of Natural Resources		100 ft	1994-7	Sample sites do not cover entire state, but randomly selected 1st-3rd order nontidal stream reaches.

Data layer	Source	Scale	Horizontal positional accuracy	Time of ground condition	Additional caveats
MBSS Aquatic Species of Concern Index	Maryland Dept. of Natural Resources		100 ft	1994-7	Sample sites do not cover entire state, but randomly selected 1st-3rd order nontidal stream reaches.
100-year floodplains	Federal Emergency Management Agency	1:24,000	40 ft	1980-95	1% annual chance of flooding. Available for Allegany, Anne Arundel, Baltimore, Baltimore City, Calvert, Carroll, Cecil, Dorchester, Frederick, Harford, Prince George's, Queen Anne's, St. Mary's, Somerset, Talbot, Washington and Worcester Counties only. Will be dropped from future GIA.
Chesapeake Bay, Chincoteague Bay, and Atlantic Ocean delineations	Maryland Dept. of Natural Resources	unknown (probably 1:24,000)	unknown	N/A	
Maryland physiographic regions	Maryland Geological Survey	unknown	unknown, but at best 431 ft	N/A	Initial map was inaccurate. It was warped to register correctly; the total RMS error was 431.426 ft in x direction, 360.720 ft in y direction.
7.5' (30-meter) Digital Elevation Models	U.S. Geological Survey	1:24,000	117.1257 ft	N/A	30-m DEM's were not available for entire state
2-arc-second (90-meter) Digital Elevation Models	U.S. Geological Survey	1:100,000	300 ft	N/A	used only where 30-m DEM's not available
Soil maps	Maryland Office of Planning	1:63,360	unknown (depends on sampling scheme)	"varied"	Use with caution
Fish blockages	Maryland Department of Natural Resources	unknown	unknown, but appears around 500 ft.	1994	Only streams used by anadromous fish were investigated. Mostly on Coastal Plain.

Data layer	Source	Scale	Horizontal positional accuracy	Time of ground condition	Additional caveats
DNR property boundaries	Maryland Department of Natural Resources	1:63,360	106 ft	1994; some more recent DNR properties were added	Boundaries for Ellis Bay WMA, Youghiogheny parcels, Gambrill State Park, Hog Marsh, Chapman's Forest, and some Patuxent parcels not in dnrlands were added.
Updated DNR property boundaries	Maryland Dept. of Natural Resources	1:63,360	106 ft	1999	Protected lands were updated in early 2000, and used in later analyses.
Wildlands	Maryland Dept. of Natural Resources	1:63,360	106 ft	1999	
Federal property boundaries	Maryland Dept. of Natural Resources	1:63,360	106 ft	1994	Not all were used (see methodology)
Updated Federal property boundaries	Maryland Dept. of Natural Resources	1:63,360	106 ft	1999	Protected lands were updated in early 2000, and used in later analyses.
Delaware protected lands	U.S. Fish and Wildlife Service	unknown	unknown	unknown	Most were outside Maryland Green Inf.
Virginia Department of Conservation and Recreation, Department of Game and Inland Fisheries, and Department of Forestry lands on Delmarva	U.S. Fish and Wildlife Service	unknown	unknown	unknown	Most were outside Maryland Green Inf.
Assateague Island National Seashore and Chincoteague NWR boundaries	U.S. Fish and Wildlife Service	unknown	unknown	unknown	

Data layer	Source	Scale	Horizontal positional accuracy	Time of ground condition	Additional caveats
Virginia TNC properties on Delmarva	U.S. Fish and Wildlife Service	unknown	unknown	unknown	Most were outside Maryland Green Inf.
Pennsylvania national wildlife preserves, national parks, national forests, state parks, state forests, and state game lands.	Pennsylvania Spatial Data Access system (Penn State University)	unknown	unknown	unknown, but before 1996	Most were outside Maryland Green Inf.
County park boundaries	Maryland Dept. of Natural Resources	1:63,360	106 ft	1994	Not all were used (see methodology)
Updated county park boundaries	Maryland Dept. of Natural Resources	1:63,360	106 ft	2000	Protected lands were updated in early 2000, and used in later analyses.
Private conservation land boundaries	Maryland Dept. of Natural Resources	1:63,360	106 ft	1994	
Updated TNC properties	The Nature Conservancy, Maryland office	1:24,000	approx 40 ft	1999	